Exoplanetary space missions

Yesterday, Today, and Tomorrow

M. Fridlund

ESA

The Past

1993: Call for proposals for Horizons2000+

- Response: Darwin Nulling interferometer

1994: Proposal (by same people Legér, Schneider et al) to augment STARS (asteroseismology) with occultation studies- approved by AWG

1995: 51 Peg is discovered by Geneva

1996: a) Roles on STARS are reveresed

b) Darwin approved as Cornerstone Candidate study

Internal Darwin study 1996 -- 1997

Evaluation of:

- Nulling interferometry
- Coronograph
- Free flying Occulter

Nulling Interferometer selected as baseline for ITT to industry

Set up of first Darwin Science Team

Alcatel Study: 1998-2000 (riders for imaging)
- Mariotti/Laurence Interferometer

Alcatel & Astrium came to conclusion that mission would be feasible after significant technology work

Selection of missions for first element of H2000+ (until 2010) selected LISA, GAIA, Bepi Colombo, JWST participation and Eddington (as reserve)

Darwin was for a few days Cornerstone 8!

Technology program was initiated

"Other worlds, with plants and other living things, some of them similar and some of them different from ours, must exist"

(Epicurus, 300 BC)

The survey committee recommends…studies of infrared interferometry, in particular with the aim of detecting Earth-like planets around other stars – Horizon 2000+ survey committee, 1994


INVESTING IN SPACE
THE
CHALLENGE FOR EUROPE

Space is so essential for the future of our civilisation that vigorous space programmes will be pursued regardless of whether Europe decides to participate. The political and economic future of Europe, however, definitively and critically depends upon its response to the space challenge! A strong European space programme is an essential ingredient for sustainable wealth and well-being, and to address a multitude of problems, both man-made and natural, on planet Earth.

LONG-TERM SPACE POLICY COMMITTEE
SECOND REPORT

➔

ACTION 1

Search for Earth-like Planets, 2000

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Darwin technology new items – useful also for Coronography

- Cryo breadboard

Formation Flying study + breadboard

Cold gas micro-propulsion P

Wavefront tilt sensorP

Phase referencing system P

Passive components (coatings, beam-splitters, ...) 1/2P

Nulling Interferometer in Integrated Optics

Single Mode Waveguide Coupling Device P

Solar Array / Sun shield P

Vibration damping P

Solid Cryogen Cooling

Micro-propulsion

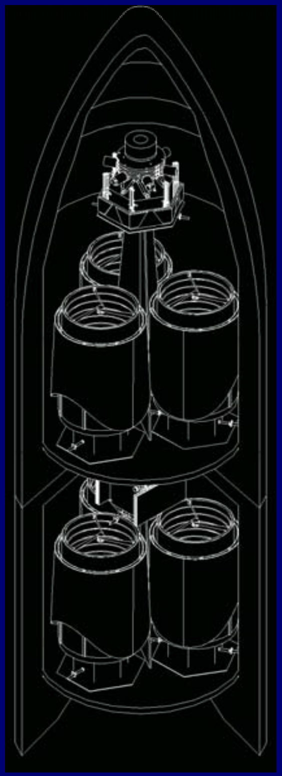
On PRISMA/PROBA

FEEP technology has high power dissipation – incompatible with payload?

-Alternative: Cold gas micro-propulsion

-Mass penalty seems acceptable

-Trade-off by Mikael Kilter (Master thesis)



Detector cooling

Two stage sorption cooler requires 14 - 16 m2 of radiators

- Combined with sun shield / solar array (D_{max}= 4m)

- Alternative for first stage: Cryostat, e.g. solid Neon

- Use Neon for micro-propulsion subsystem?

SMART-3

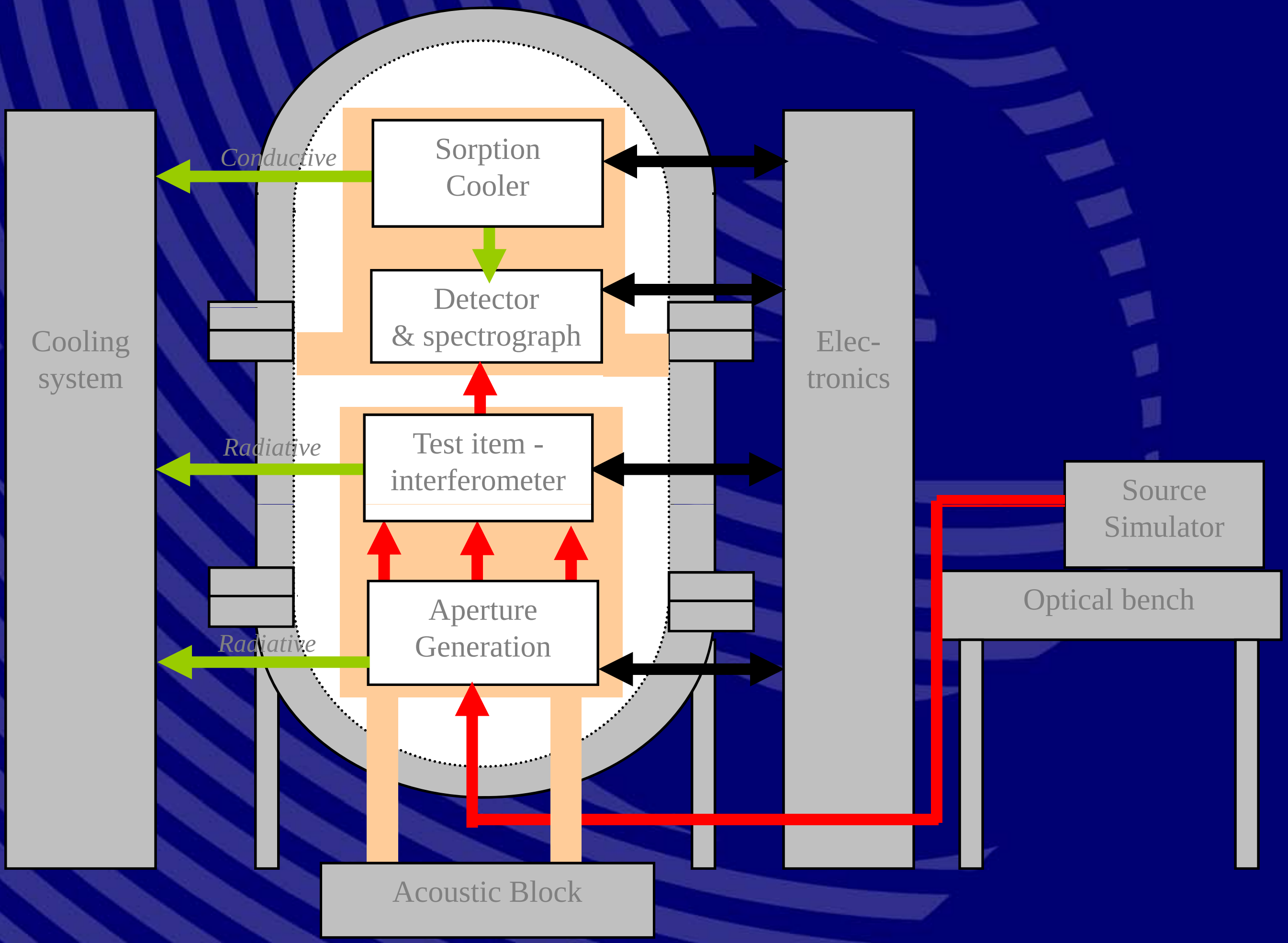
Formation Flying mission coordination

- SMART-3, DARWIN demonstration

-PROBA-3, general FF (low-cost, LEO?)

Replaced by PRISMA/PROBA

Cryogenic Interferometry Facility - CIF



Tech Dev Schedule

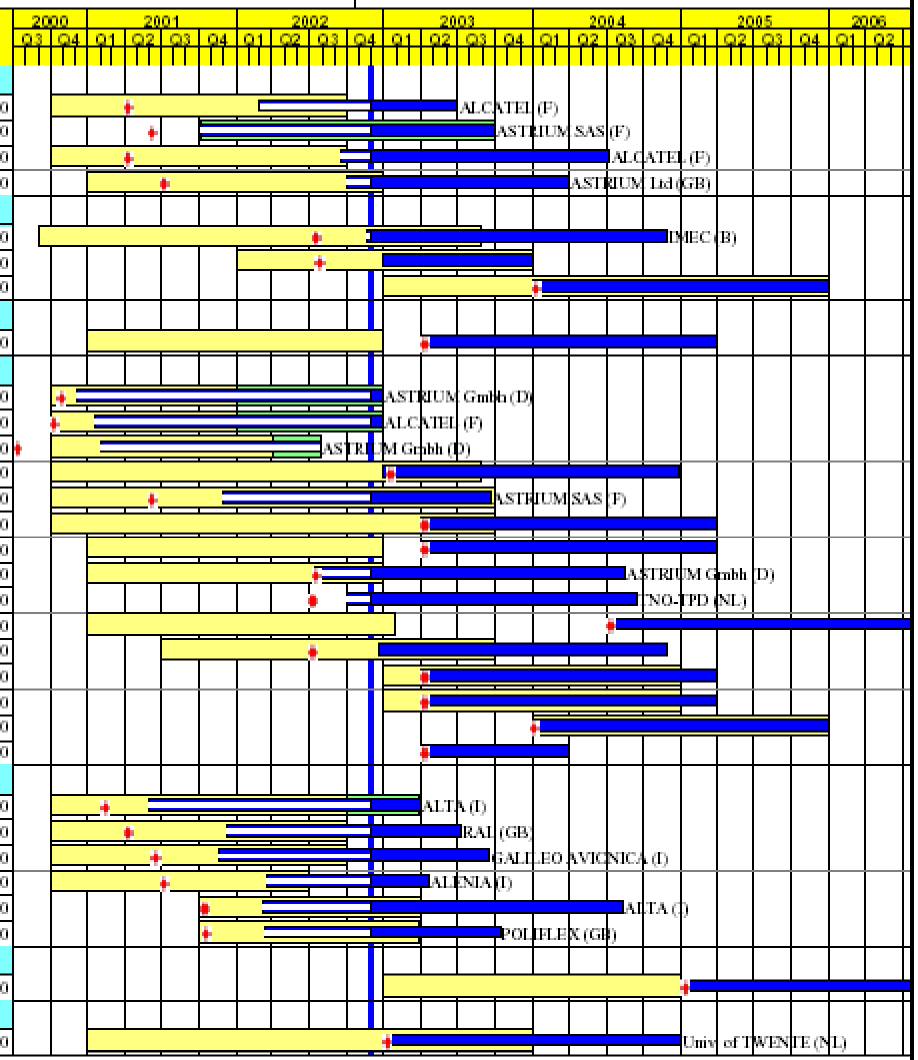
- Agreed Completion
- Baseline ESA/IPC (2000)3, add.3 Nov 2000
- Current Plan
- Progress Bar
- Critical Activity

DARWIN Technology Schedule

Version: V 1.09, NOV 2002

Sheet 1 of 1

Activity Description	Covered by	SCI-REF	TOS-REF	Pro-gram	Cost
AOCS & GNC					
Formation Flying RF Subsystem		ID-AO-01	ETT-062	TRP	750
Interferometry Constellation Control		ID-AO-02a	ESC-001	TRP	440
Interferometry Constellation Control		ID-AO-02b	ESC-001	CTP	440
Satellite Deployment Control for Interferomet...		ID-AO-03	ESC-002	TRP	300
Detectors					
Far Infrared Linear Detector Array		ID-DE-02	EEO-021	TRP	750
Fringe Sensor		ID-DE-03	MMO-668	TRP	250
Detector Read-out Electronics		ID-DE-04	EEO-048	TRP	350
Image Processing					
Reconstruction of Nulling Interferometer Images		ID-IP-01		D/SCI	300
Optics					
Multi Aperture Imaging Interferometer		ID-OP-01a	97/XAL01	TRP	400
Multi Aperture Imaging Interferometer		ID-OP-01b	97/XAL01	TRP	400
High Stability Laser for Space Interferometry	LISA	LI-OP-01	98/XAL01	TRP	0
Integrated Optics		ID-OP-02		TRP	750
High Precision Optical Metrology		ID-OP-03	MMO-630	TRP	1,000
Optical Components for Interferometry		ID-OP-04	MMO-633	TRP	450
Fiber Optics Wavefront Filtering		ID-OP-05	MMO-632	TRP	500
Single Mode Fibers for DARWIN (with Astrium)		ID-OP-06a	EEO-047	TRP	500
Single Mode Fibers for DARWIN (with TNO-TPD)		ID-OP-06b	EEO-047	TRP	500
Proof of Nulling Interferometers		ID-OP-07	MMO-631	CTP	1,600
Achromatic Phase Shifter for Nulling Interfer...		ID-OP-08	EEO-036	TRP	750
High Stability Optical Benches for DARWIN		ID-OP-09	MMO-634	TRP	500
Large Optical Assembly for DARWIN		ID-OP-10		CTP	700
Manufacture Reproducibility for Optical Elements		ID-OP-11		CTP	200
Optical Delay Lines		ID-OP-12		TRP	300
Propulsion					
Development of Integrated FEEP Cluster Systems	SMART-2	C01	MPE-871	TRP	0
Development of FEEP Neutralisers	SMART-2	C02	MPE-878	TRP	0
FEEP PCU High Resoltion for High Efficiency	SMART-2	C03	ESP-022	TRP	0
Thrust Measurement System at MicroN Levels	LISA	LI-PR-01		CTP	0
Low Thrust Propulsion System	LISA	LI-PR-04a		CTP	0
Low Thrust Propulsion System	LISA	LI-PR-04b		CTP	0
Structure & Mechanisms					
Solar Array Sun Shade		ID-ST-01	MMS-987	TRP	800
Thermal					
Sorption Cooler (4°K)		ID-TH-01	MCT-693	TRP	600



ESA Coronography

Workshop 2 – 5 February 2004 in Leiden (Lorenz center) – Chair Andreas Quirrenbach

- ~40 people

- Target: To bring US and EU together and explore collaboration

- Explore national funding

- Suggest ESA technology development

Programme in a Nutshell

Technology Research Programme

SMART 3
Formation Flying precursor and interferometry

FINCH
system simulator formation flying & optical

Nulling breadboard

COROT & Eddington
stellar occultations

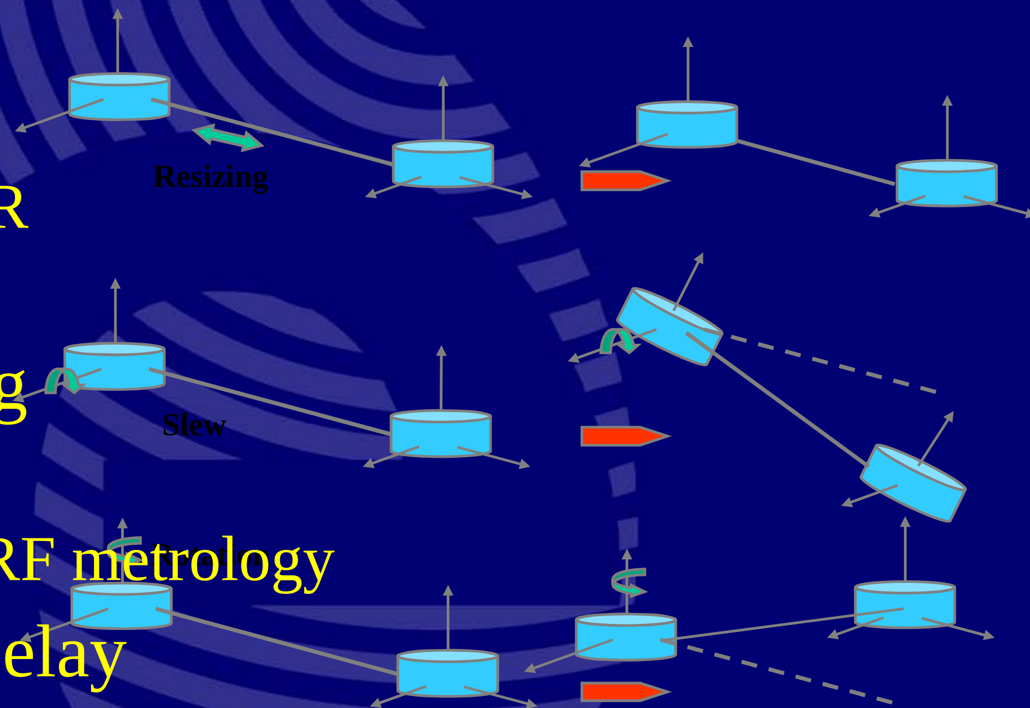
GENIE
stellar nulling interferometry

FINCH

(Fast Interferometer Characterisation)

- Optical
  - Building on ESO's simulator of VLTI
  - SW designed with DARWIN in mind
- Formation Flying
  - GNC simulator developed in technology programme
- End-to-end simulator
  - Allowing system couplings to be identified
  - Developed throughout mission lifetime
  - Open access

DARWIN on SMART-3

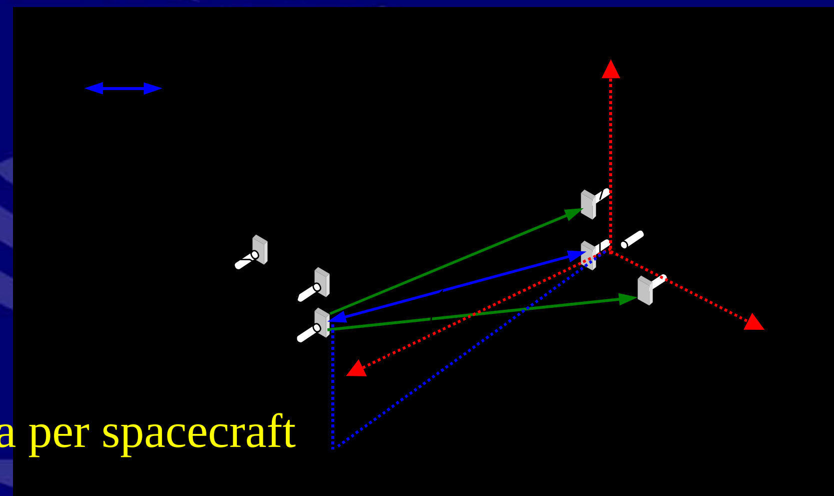


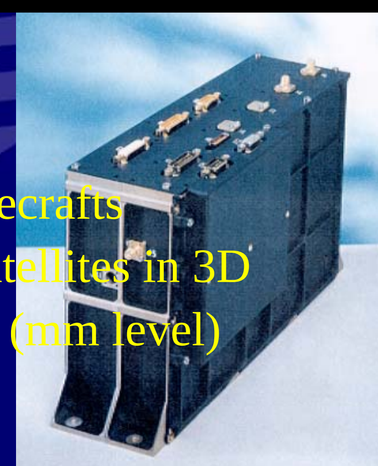
- Formation flying
  - –Deployment
  - –Collision avoidance, FDIR
  - –RF metrology
- Precision formation flying
  - –Accuracy (~ 1 micron)
  - –High precision Optical - RF metrology
- Verify need for Optical Delay
  - –ODL used to find fringes (baseline)
  - –Micropropulsion used to find fringes
- Technology relevant to wide range of missions
  - –XEUS, Planet Imager, Earth Observation (GEO) and
  - –Close Flying Comms Sat in GEO

ON PRISMA

RF metrology

- The FF RF Subsystem provides for the formation
  - relative position, velocity, attitude, attitude rate
  - local time
  - communication link
- Performance
  - Elevation and azimuth: 0.5 deg
  - Range 1 cm
- Equipment
  - Minimum of 2 Tx/Rx and 5 Rx antenna per spacecraft
  - S-band (L-band protected)
  - Dual frequency
- Drivers
  - Roboustness: Navigation Processing in all spacecrafts
  - Full visibility: Relative position of 2 satellites in 3D
  - Calibration: Multipath and RF path calibration (mm level)
  - Collision avoidance: Fast navigation solution





Receiver derived from L-band equipment

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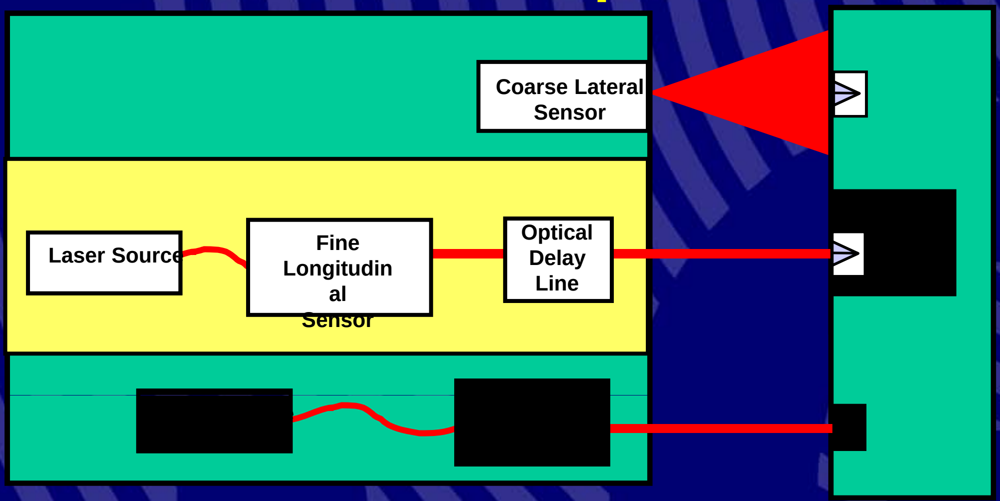
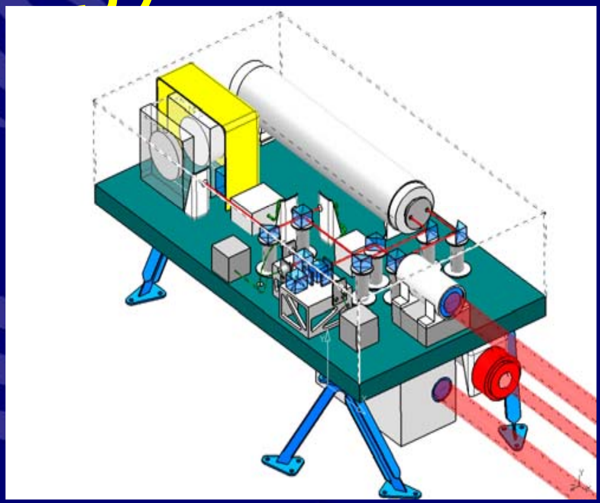
Optical Metrology





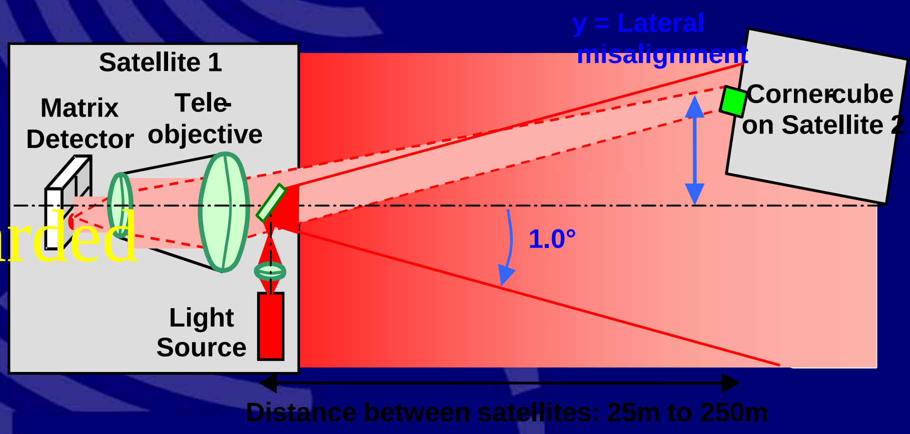
- Coarse Lateral
- Fine Longitudinal
- Optical Delay Line

- Fine Lateral
- Absolute Longitudinal
- Frequency Scan Interferometer
- Dual Frequency Interferometer

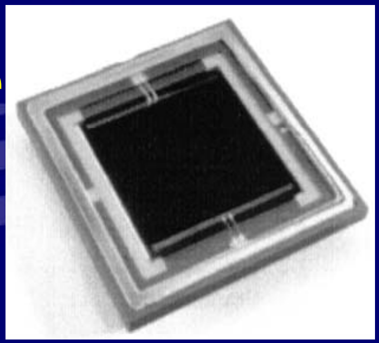
Lateral Metrology

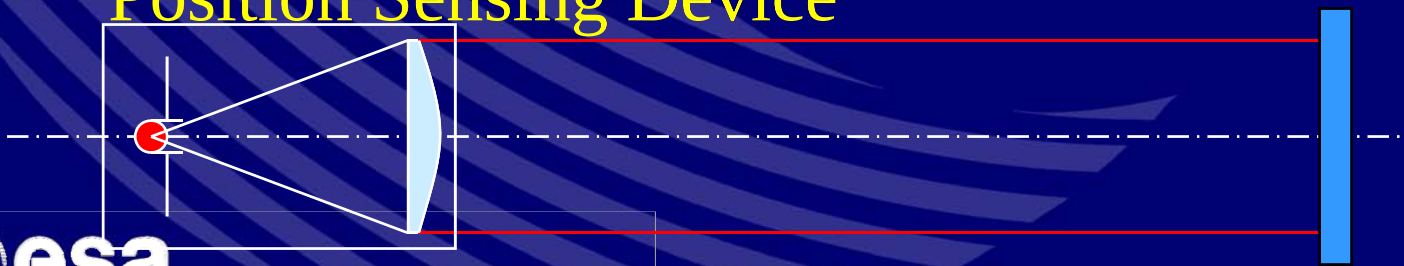
ON PRISMA/PROBA3

- Coarse Lateral Sensor
  - Accuracy +/- 1 mm
  - Designed but not breadboarded
  - Non-critical

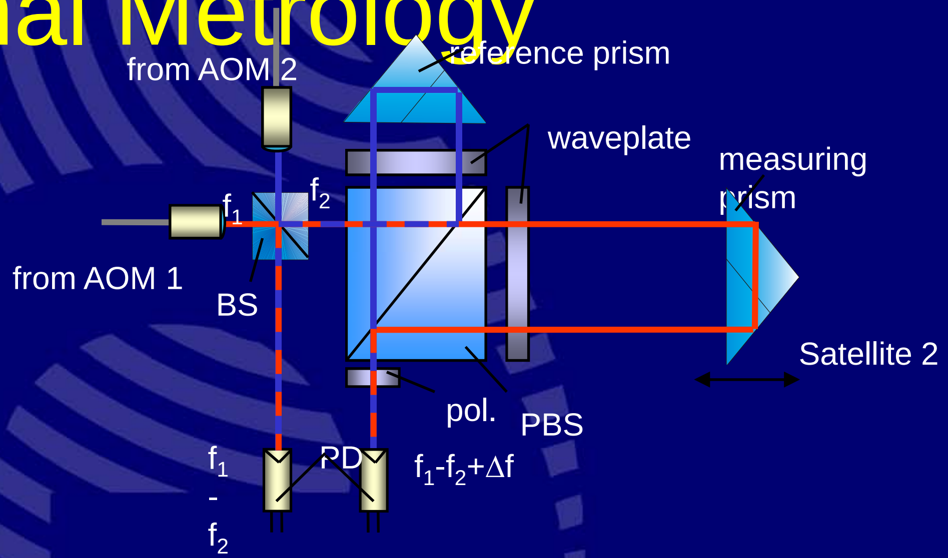


- Fine Lateral Sensor
  - Accuracy 30 microns at 250 m distance
  - Collimated laser beam
  - Measurement of the Spot center on a Position Sensing Device

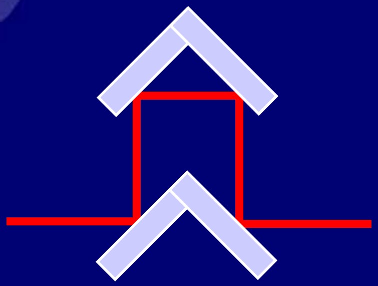




Longitudinal Metrology



- Optical Delay Line
  - stabilisation of fringes
  - stroke: 10 microns
  - Actuator: piezo
-



GENIE - status

- Evaluation phase ➔ 2 contracts
  for separate 12 months
  definition studies ➔

1) To expensive

2) closed down in 2006

The Present

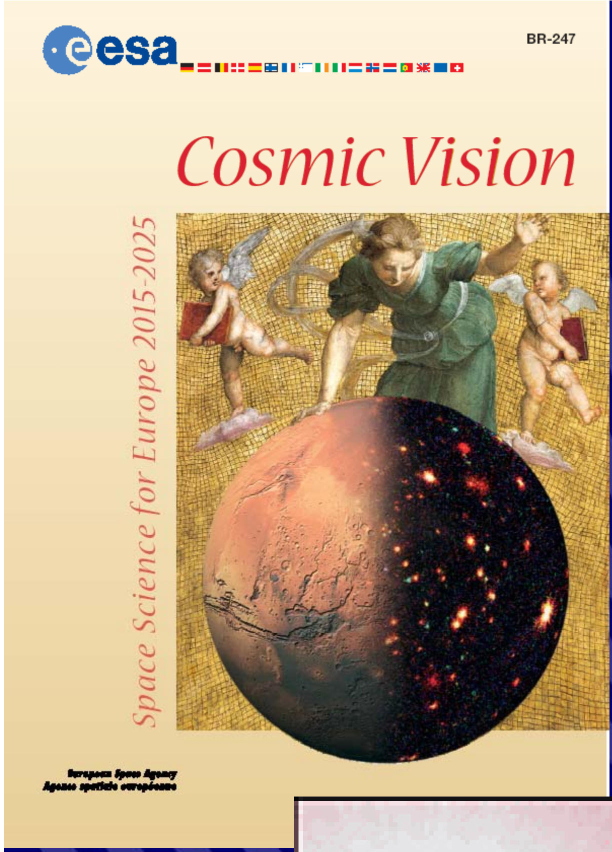
Cosmic Vision

ESA's new scientific plan

Runs 2015 - 2025 (and beyond)

Adresses themes with variety of missions

Currently: L (650M€), M(300M€), O(portunities) (<150M€)



Cosmic Vision is centered around four Grand Themes:

1. **What are the conditions for planet formation and the emergence of life?**
   - **From gas and dust to stars and planets**
   - **From exo-planets to biomarkers**
   - **Life and habitability in the Solar System**
2. **How does the Solar system work?**
3. **What are the Fundamental Physical Laws of the Universe?**
4. **How did the Universe originate and what is it made of?**

Proposed strategy:

First: In-depth analysis of terrestrial planets (Darwin / NIRI)

Next: Understand the conditions for star, planet and life formation (Far IR observatory / Solar Polar Orbiter)

Later: Census of Earth-sized planets & explore Europa (Terrestrial Planet Astrometric Surveyor / Europa orbiter / lander)

Finally: Image terrestrial exo-planet (beyond 2025) (Large Optical Interferometer)

‘Big Questions’

1. “What is the uniqueness of our own Earth?”
   - The searching for, study & characterization (incl. Atmospheres)
   - of Terrestrial Exoplanets (TE’s)
2. “Are we (lifeforms) alone?”
   - The habitability of these worlds, search for biomarkers
3. “What is our past & future?”

   The formation of planets

   The evolution of planetary systems

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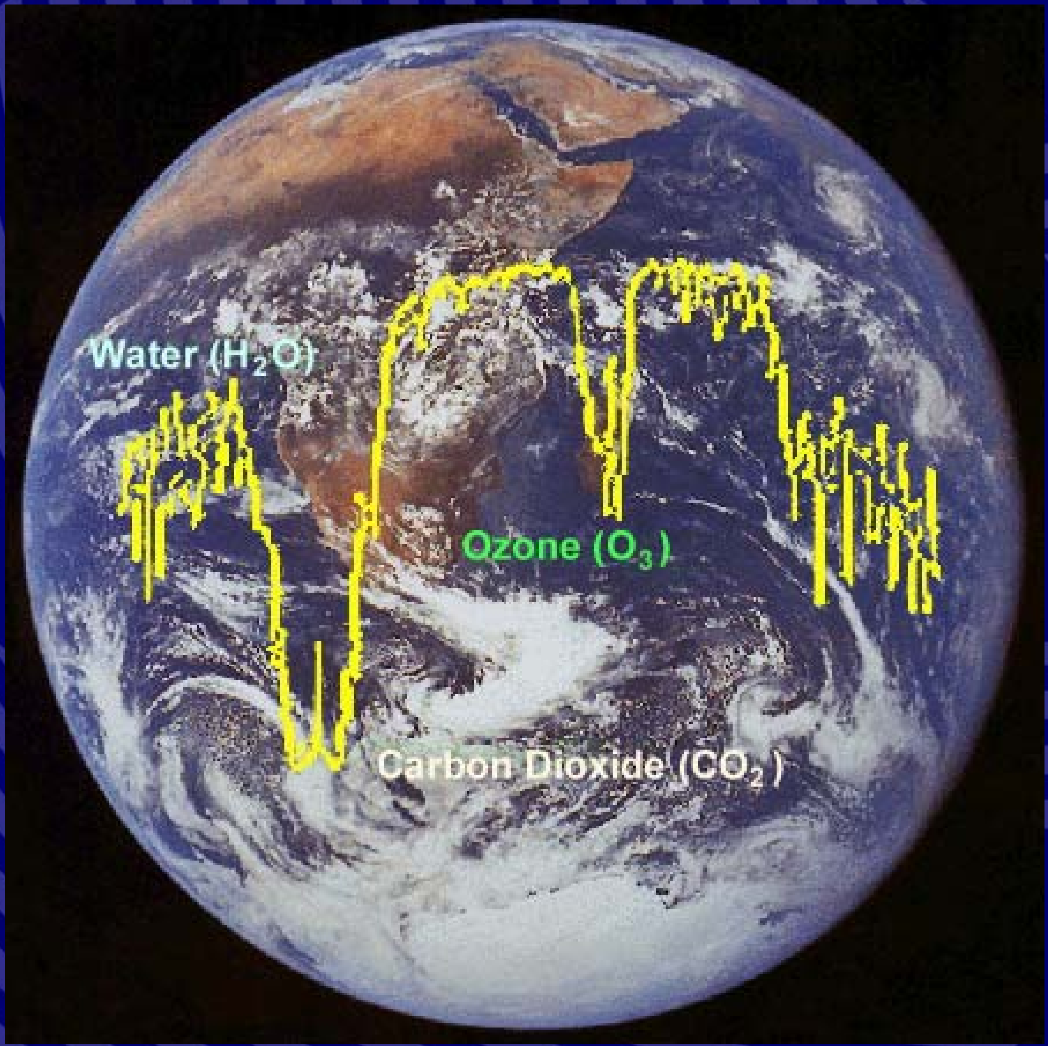


The Ultimate Goal

First: In-depth analysis of Earth-like planets

What strategy?

- Search for rocky planets and determine if they are common or rare
- Determine the physical conditions of and on these planets
- Determine whether these planets are in principle habitable
- Find out if these planets have life on them
- To place ourselves in context we need

Comparative Planetology

How do we do it?

First round of CV2015:

About 20 exoplanetary missions (theme 1) in category L & M were proposed

Including Darwin

Darwin was highly ranked scientifically but deemed not technologically mature for 2018

PLATO was selected for an M-class study

And we have CoRoT…..


COROT, COnvection, ROtation
& Transits exoplanétaires
cnes
esa

COROT:

- S/C 4.2m x 1.9m x 9.6m, 650kg, 530w
- Payload
    - CoRoTel, afocal, 27cm aperture, Baffle
    - CoRoTcam, dioptric, 4 CCD frame transfer 2048 x 4096
    - CoRoTcase, electronics box
- Short integrations (20d -- 60 days) on asteroseismology fields in between 150 days on exo-fields

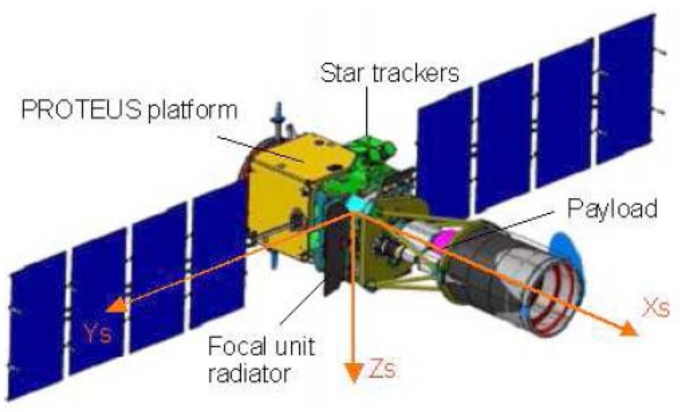
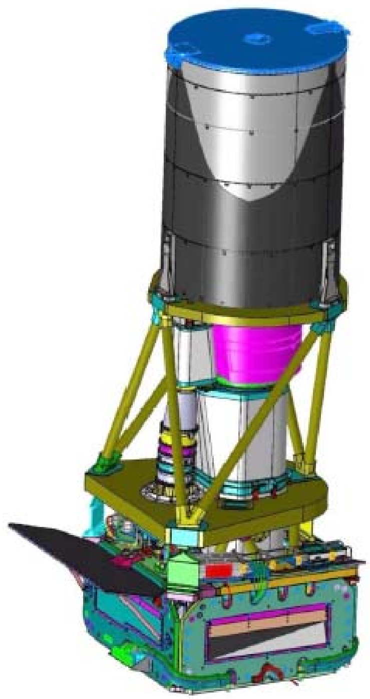
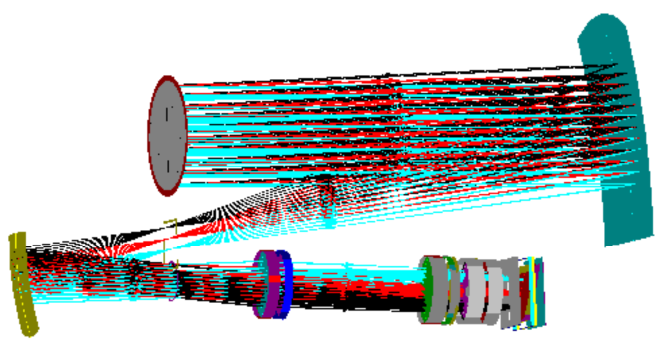


Figure 4. Satellite overview (4.20 mx9.60m)

Instrument





- Optical layout
- 27 cm main mirror
- 2 focal planes
  - 1 for exoplanets
  - 1 for asteroseismology
- Prism in front of exoplanetary field
  - Provides short spectra to discern transits from activity

Basics

Weight 600kg, Dimensions 4.2m by 1.9m, Power generation 530W Based on CNES PROTEUS space craft

Pointing accuracy = 0.”2

Payload (= telescope) 300kg, Data rate 900Mb/day

Nominal mission 2.5 years, Extended mission added 3.5 years

Scientific Program

- Asteroseismology
  - Exploratory program studies astroseismological properties for a large number of stellar types (0.5 mHz)
  - Detailed program follows individual objects with high s/n for long periods (2-4 months) (0.1 mHz)
  - 10 primary up to 800 secondary targets per field
- Planetary transits
  - 150 day observations of each field (180 possible)
  - Color information
  - Short periods allow small planets to be detected
  - Up to 12000 targets per field

Plus additional science plus support program

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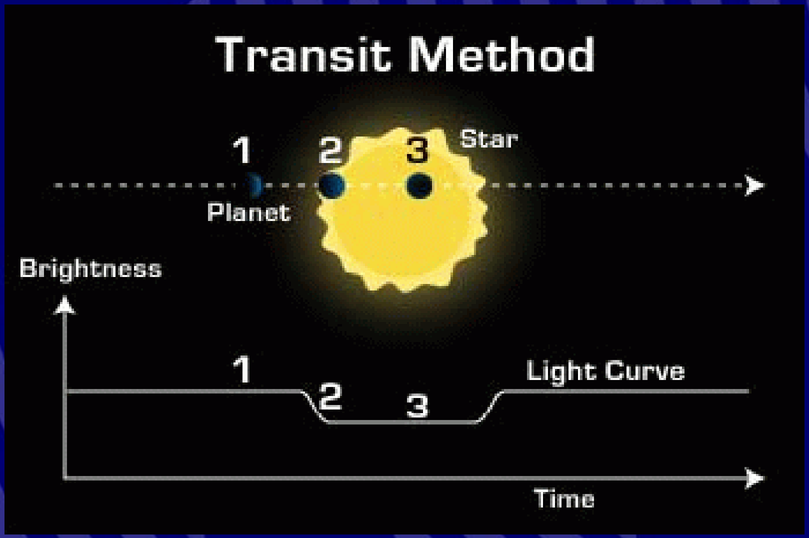
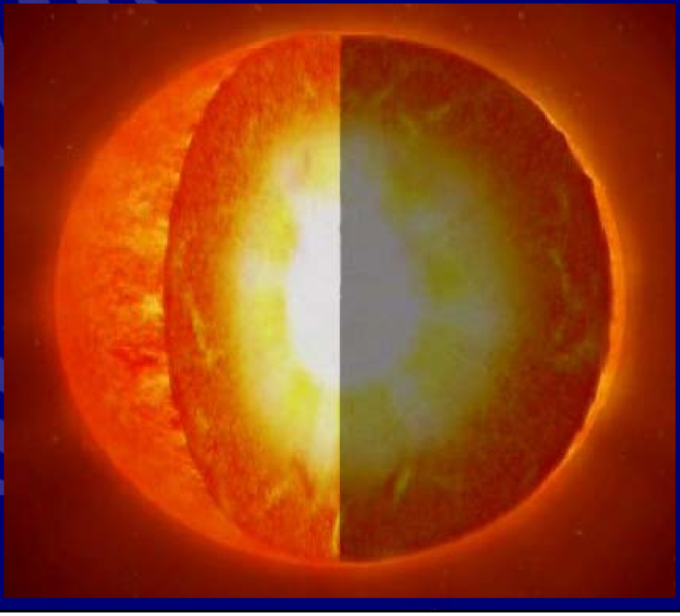
Objectives





COROT has two objectives:

- Searching for planets of the a type similar to our own Earth (so far unknown around other stars
- Studying the inner parts of stars (for the first time) by measuring the changes in light output caused by acoustical sound waves travelling through the star.

COROT is essentially a very precise light-meter (photometer). COROT can measure changes in stellar flux of 1 part in 100 000!

Can discriminate between colours ==> COROT can tell what the cause of variations in stellar flux are:

a) Intrinsic changes caused by activity or by waves travelling through the star

b) Occultations by a (small) planetary body passing in front of the star

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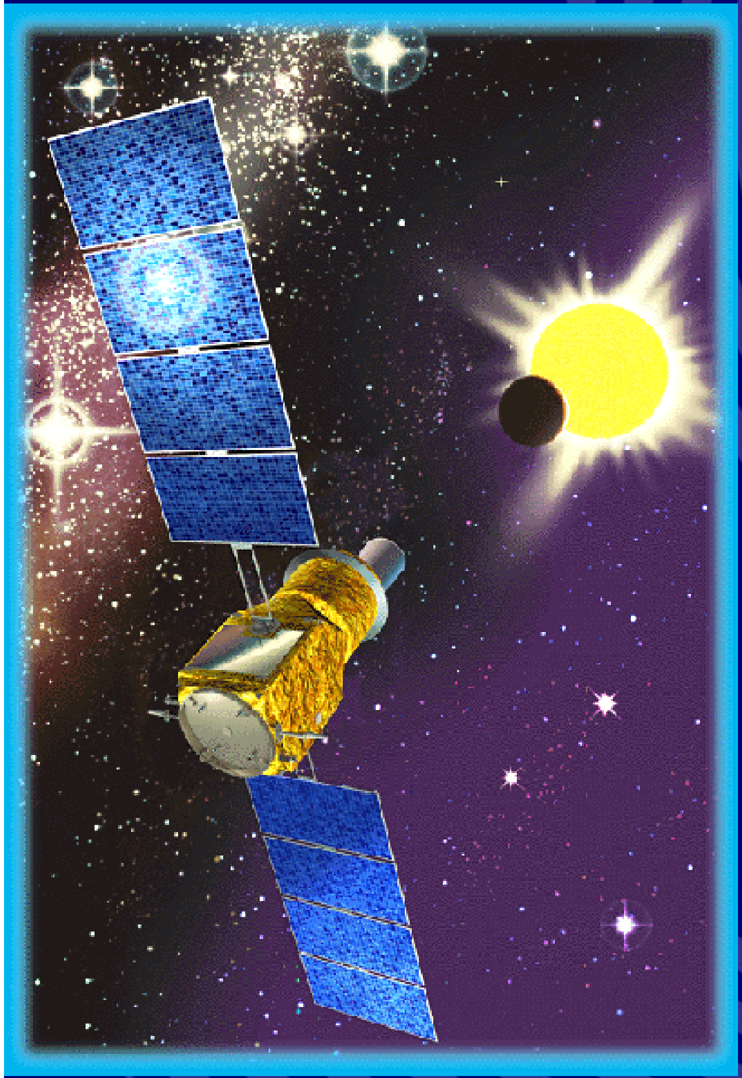
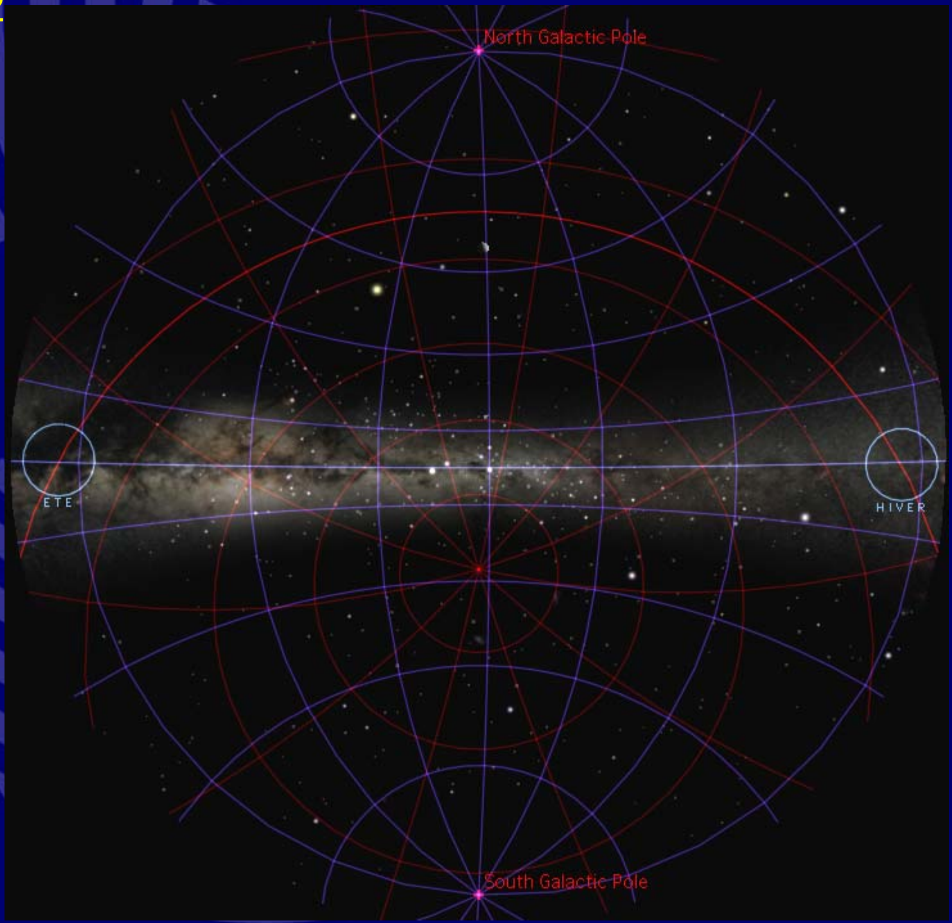
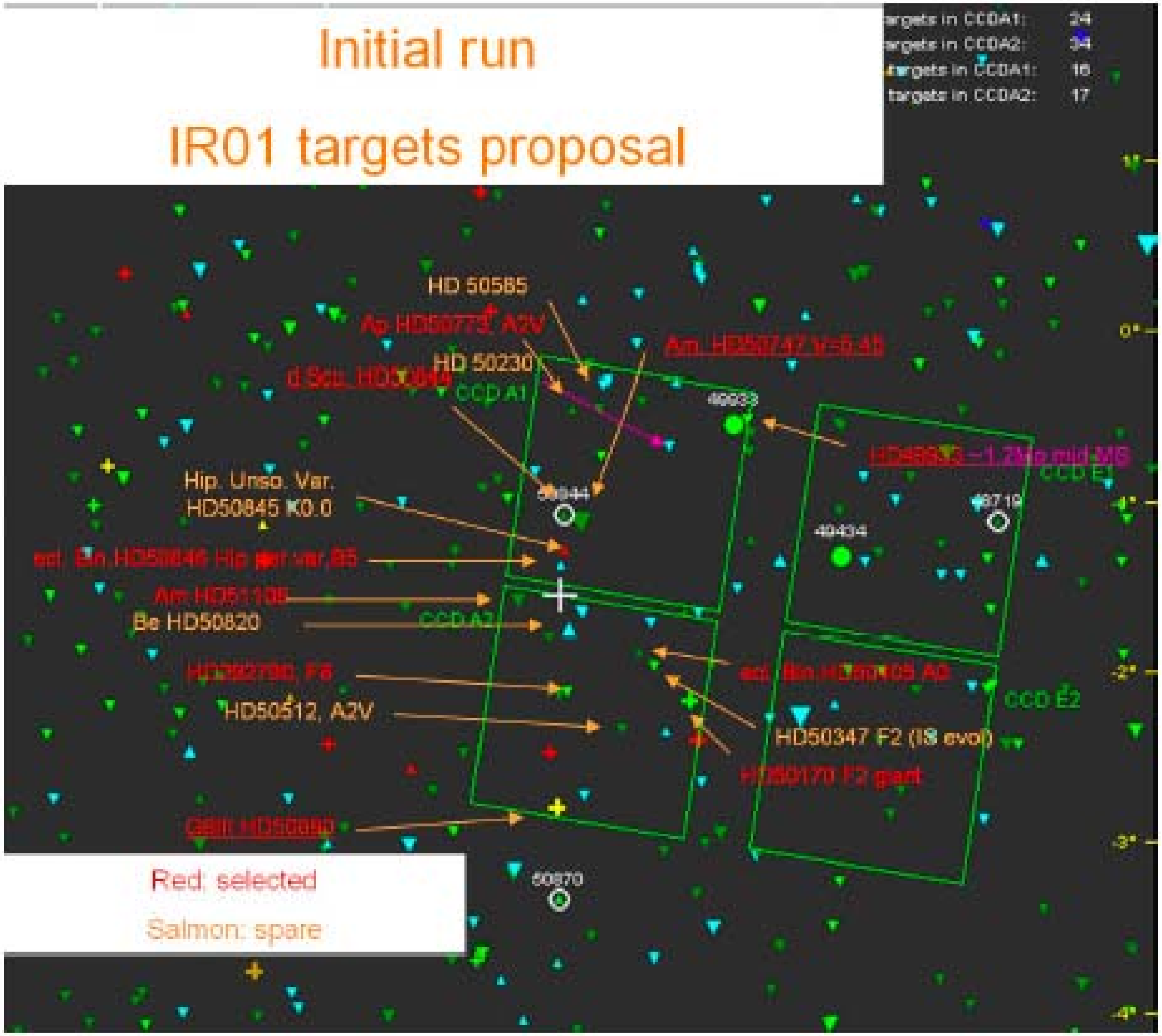
Basics 2





Initial run

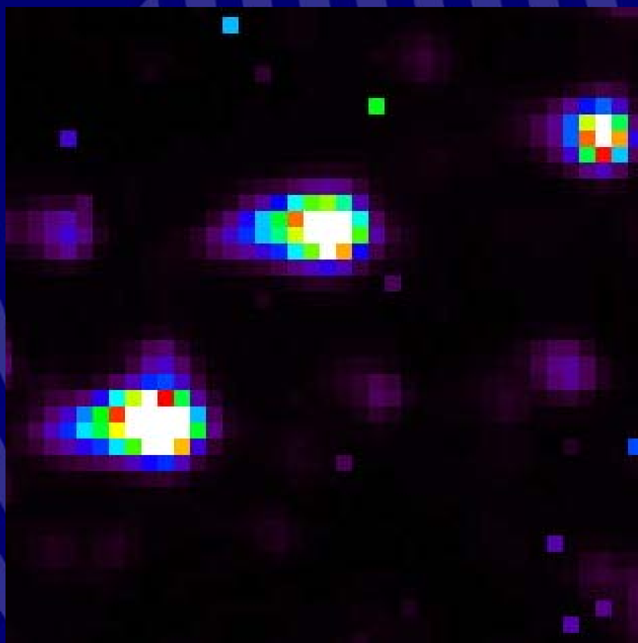
IR01 targets proposal

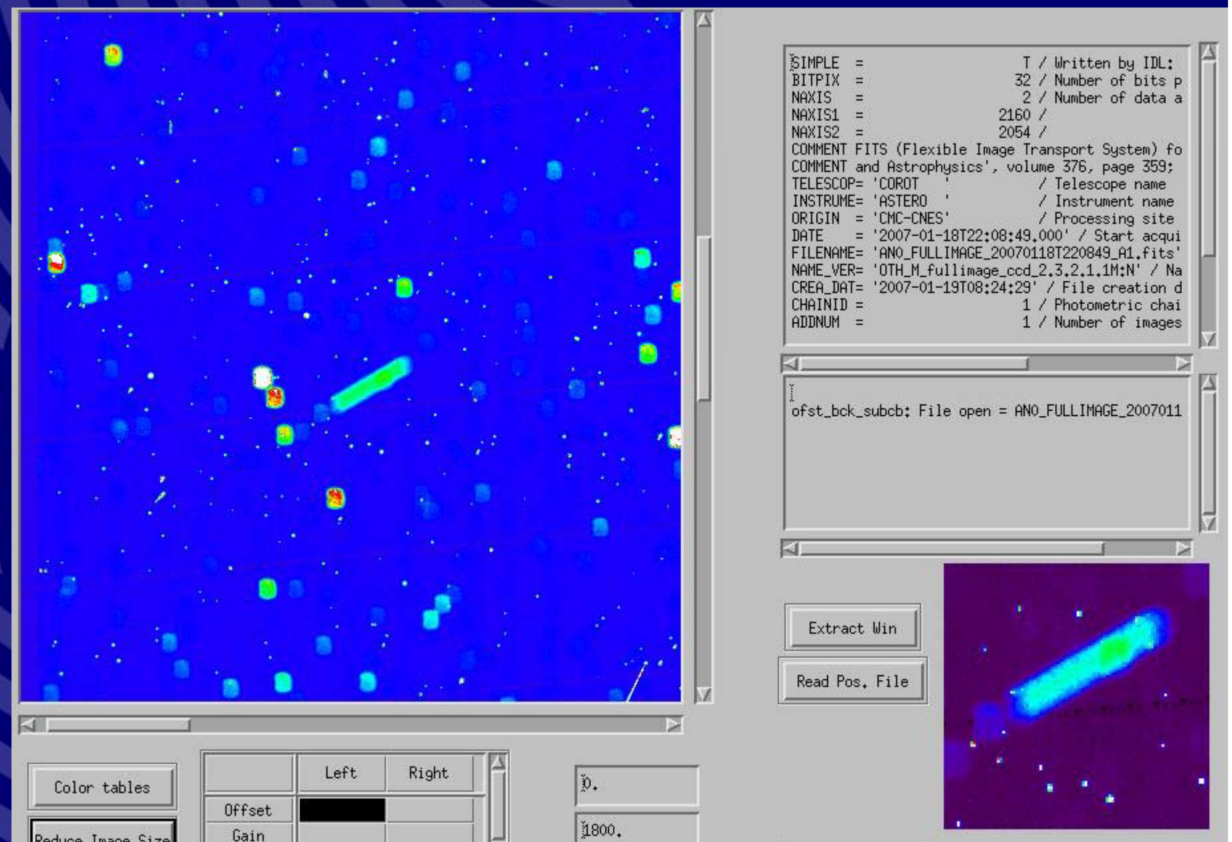


Status

- Launched on first second of first launch window on 27 December 2007
- Launch sequence nominal. Orbit perfect.
- Solar panels deployed. Space craft turned ON, Instruments turned ON. All systems nominal
- Telescope hatch opened on 16 january
- Verification of observing systems 16 january -- 31 january
- Beginning of science observations on february 1

Lightcurves and UFO's observed

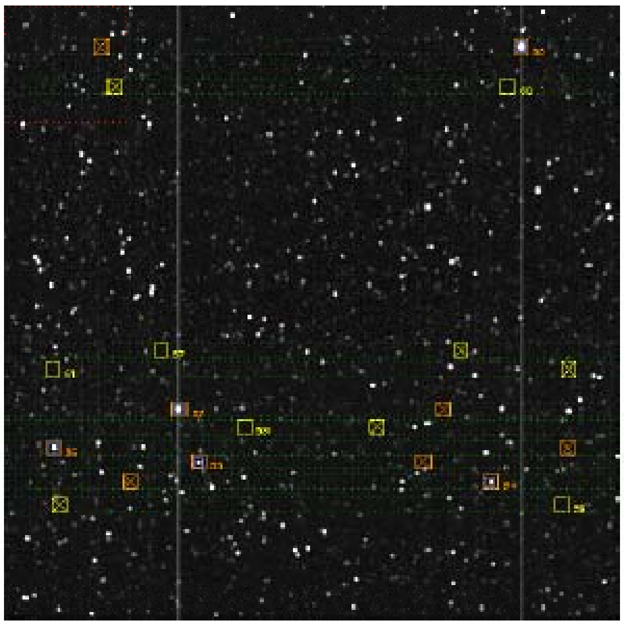




Imagettes and lightcurves - with color

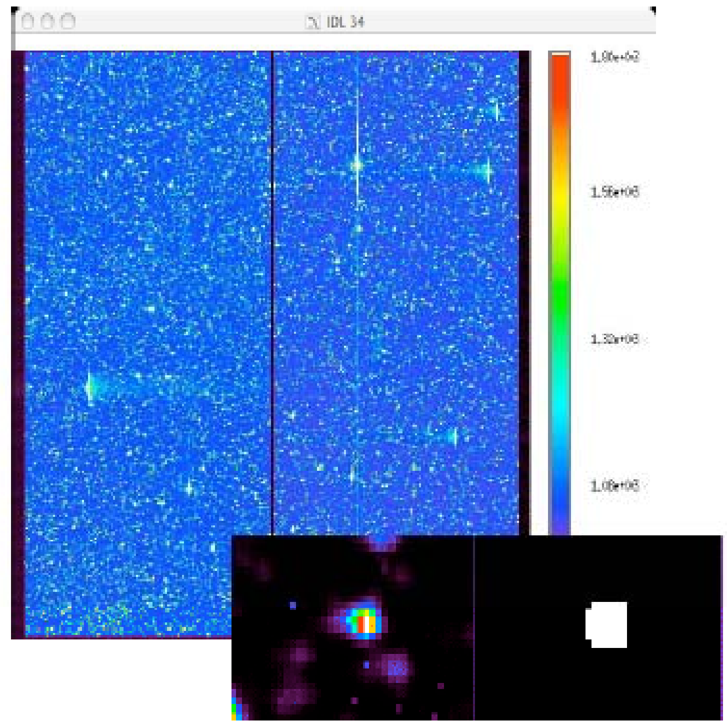
Full images, windowing and target selection

Seismology detector (Vincent Lapeyrere)



- 10 bright stars
- 10 background windows

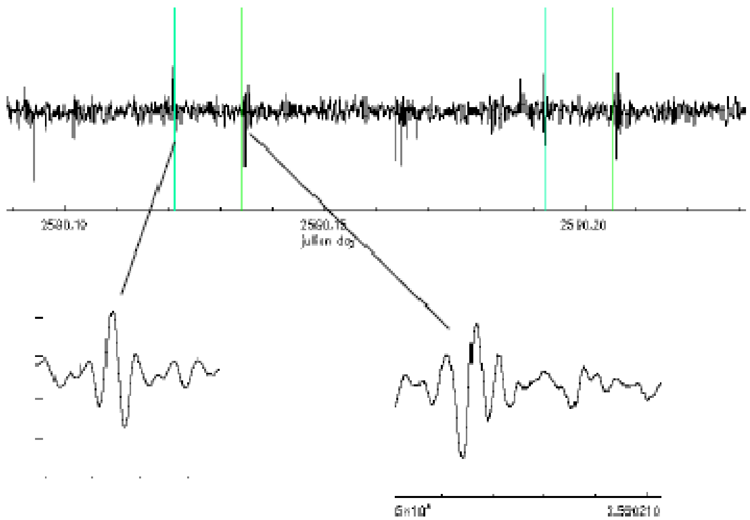
Exopplnat detector (Farid Karioty)



- 11600 faint stars
- 400 background windows

SCAO

Barycenter X of the stellar image

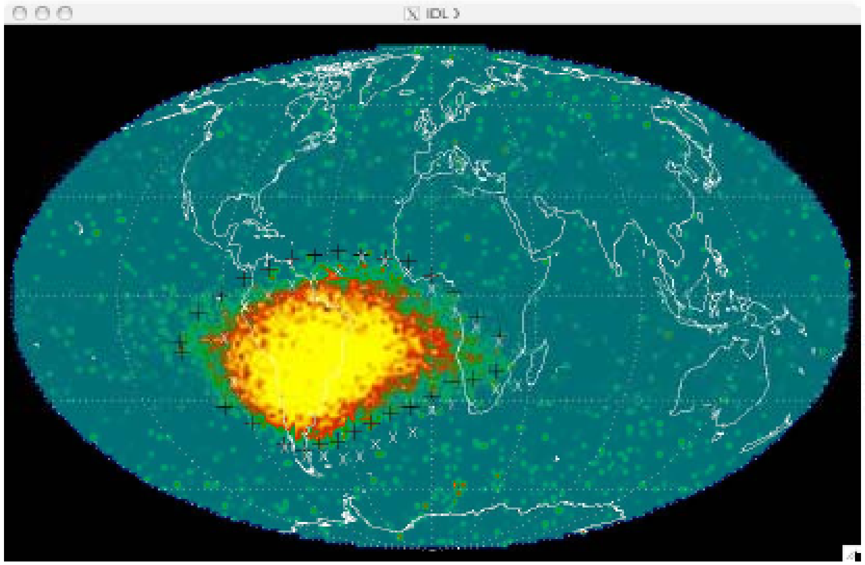


Vibrations due to the entrance and exit form ecclipses

Stability performances :
x axis: rms 0.12 pixel
y axis: rms 0.15 pixel

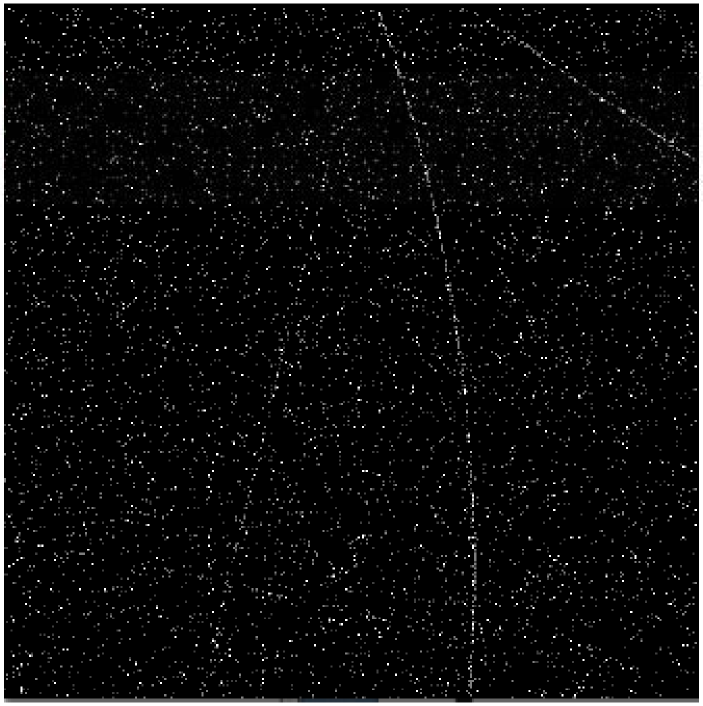
~ 0.3 arc sec.

Radiations: SAA

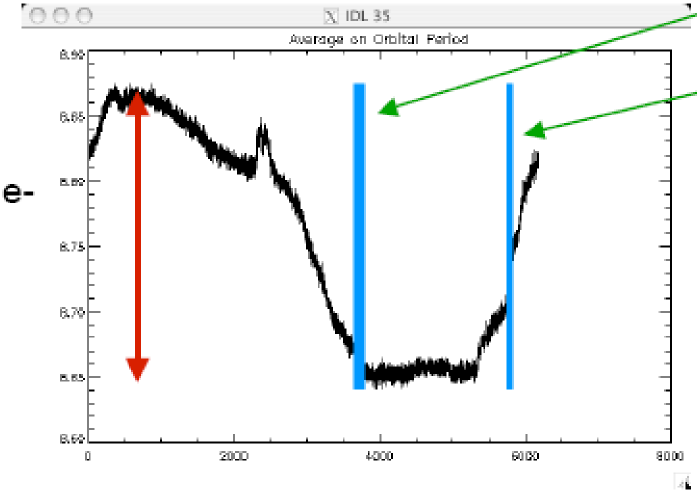


Position of the SAA measured with CoRoT data. Position shifted towards NW of Approximately 5 degrees with respect to the AP8min model (Leonardo Pinheiro)

Example of a charge deposit in an exo CCD (Farid)



Straylight background



0.4 e-

Eclipses
Input

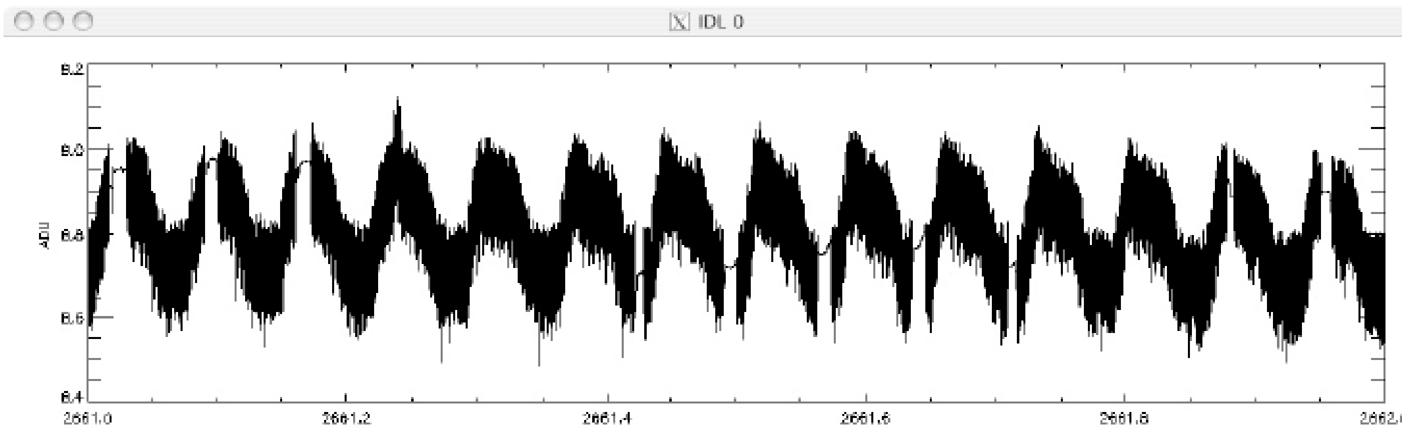
output

Averaged over one orbit

Smaller than expected !
Baffle efficiency > 10^{-12}

Duty cycle

Data losses are mainly due to the SAA crossing: **6%.**
Hot pixels flux 10 times more than expected



Example of background data corrected from the protons perturbations

Other random events contribute to 1 to 2%.

Duty cycle 92%

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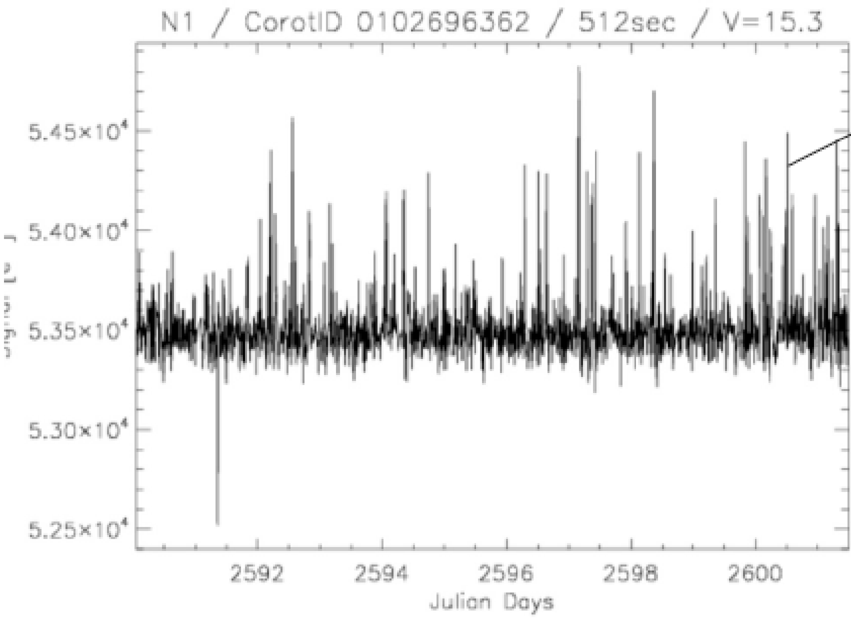
Performances exo field



Without corrections the noise
is close to the photon noise

Magnitude 15.4

Without correction
rms 1170 ppm

Photon noise:
rms 1080 ppm

Magnitude 12.3

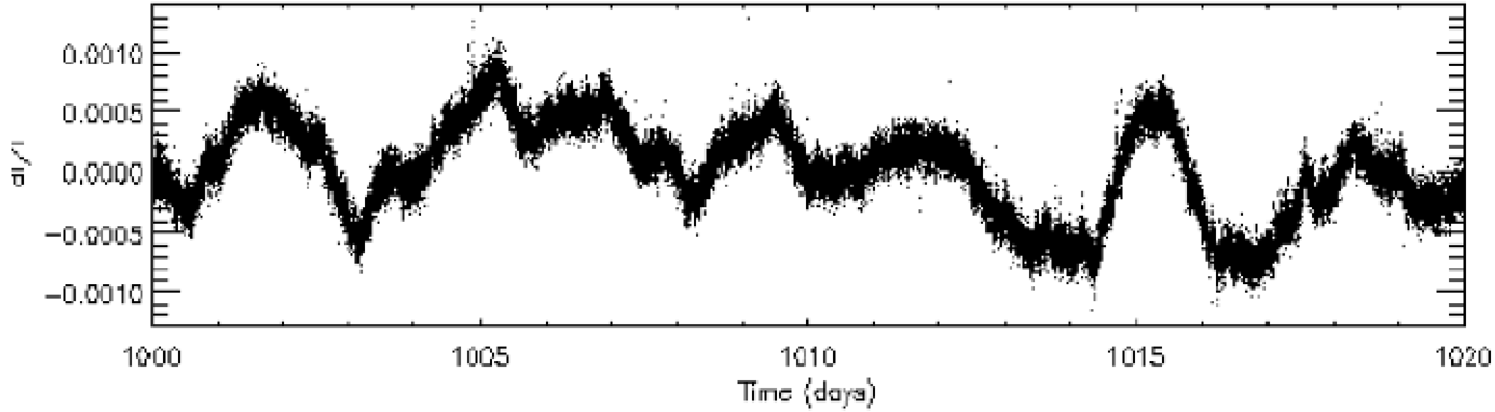
Without correction
rms 400 ppm

Photon noise:
rms 300 ppm

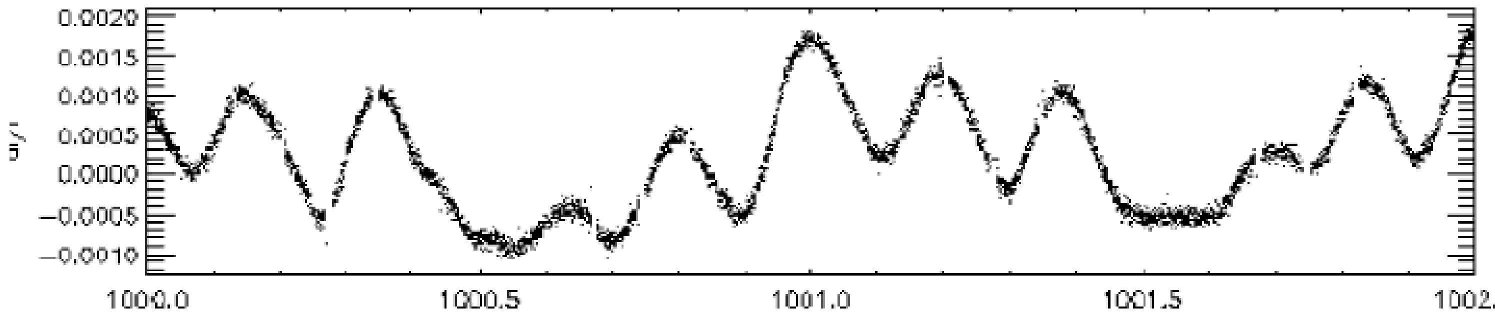
Light curves in the sismo field (1)

1 point every 32 s. abscissa days, arbitrary unit, ordinate relative flux

A 6th mag F-type star showing daily variability below the 10^{-3} level

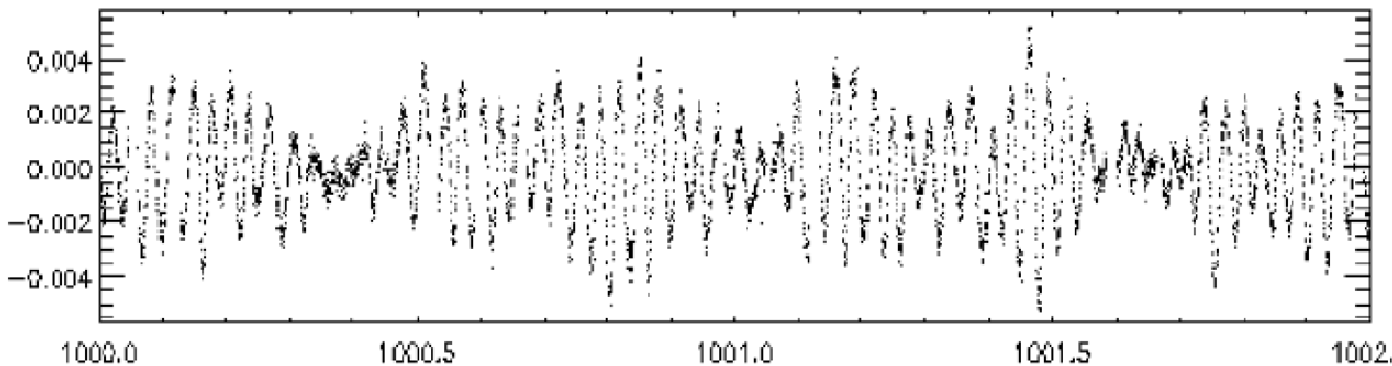


A 6th magnitude A star showing variability below the 10^{-3} level on a few hours

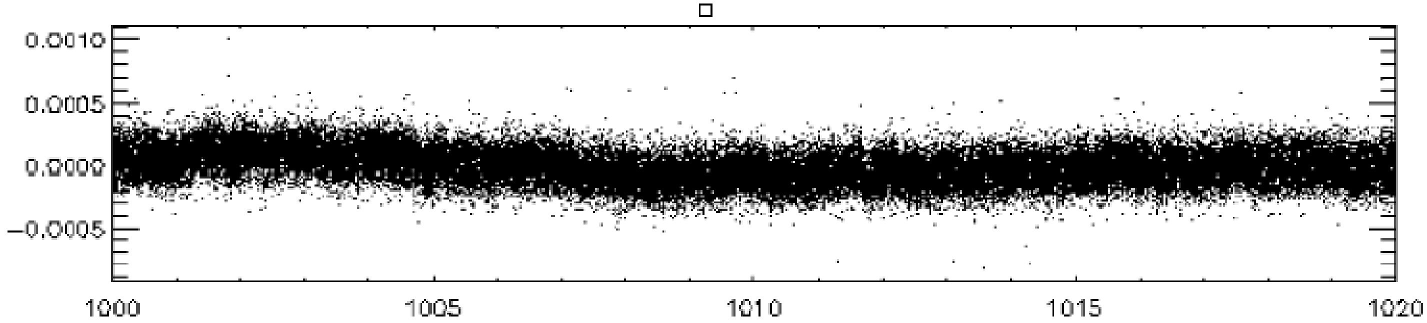


Light curves in the sismo field (2)

A 9th magnitude suspected delta Scuti star from ground based preparatory observations, showing beat phenomena at a few 10^{-3}



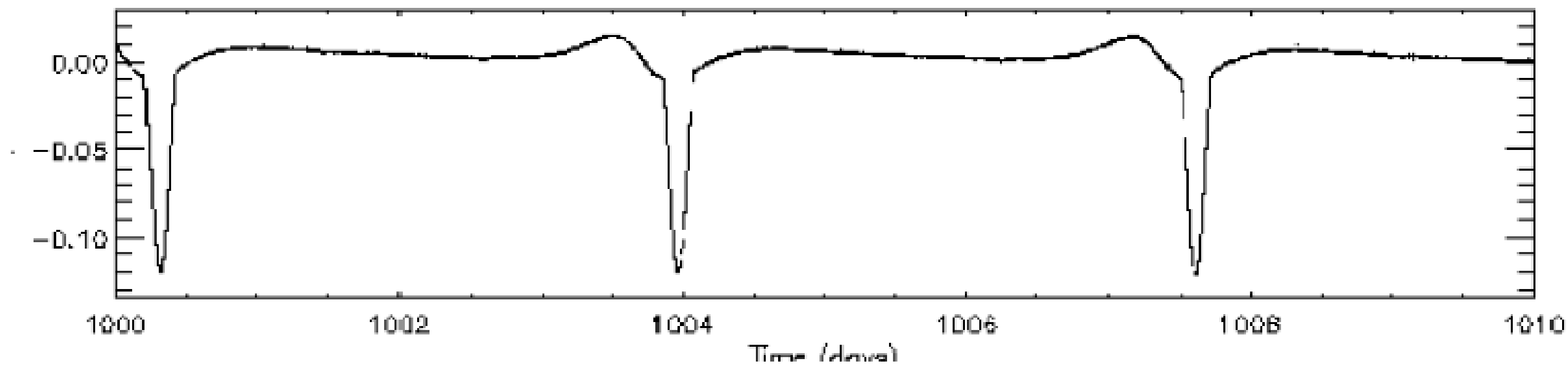
A 7th magnitude giant F star showing very low dispersion of a few the 10^{-4}



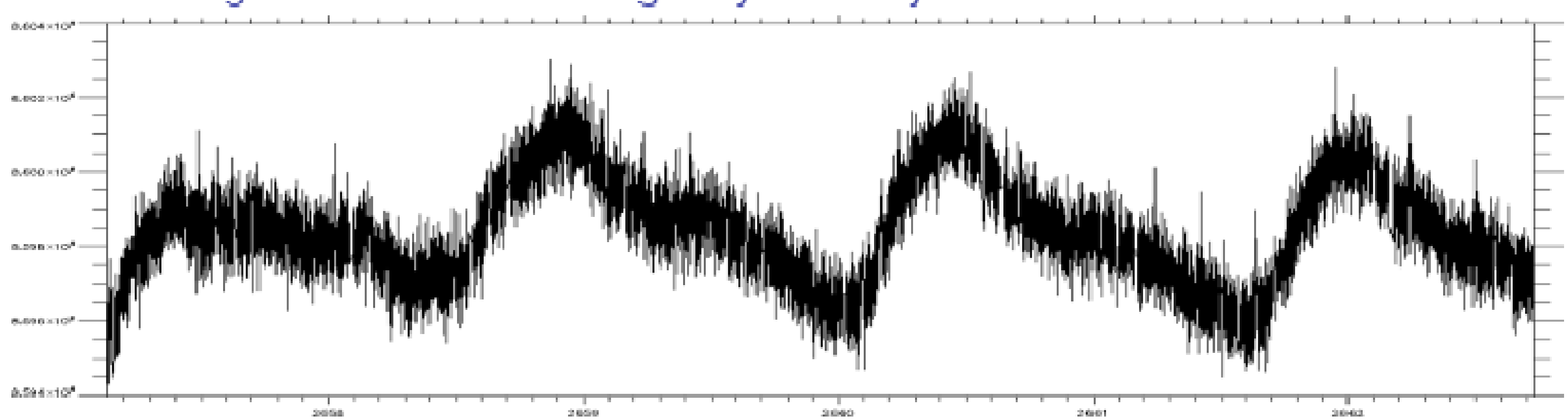
esa

Light curves in the sismo field (3)

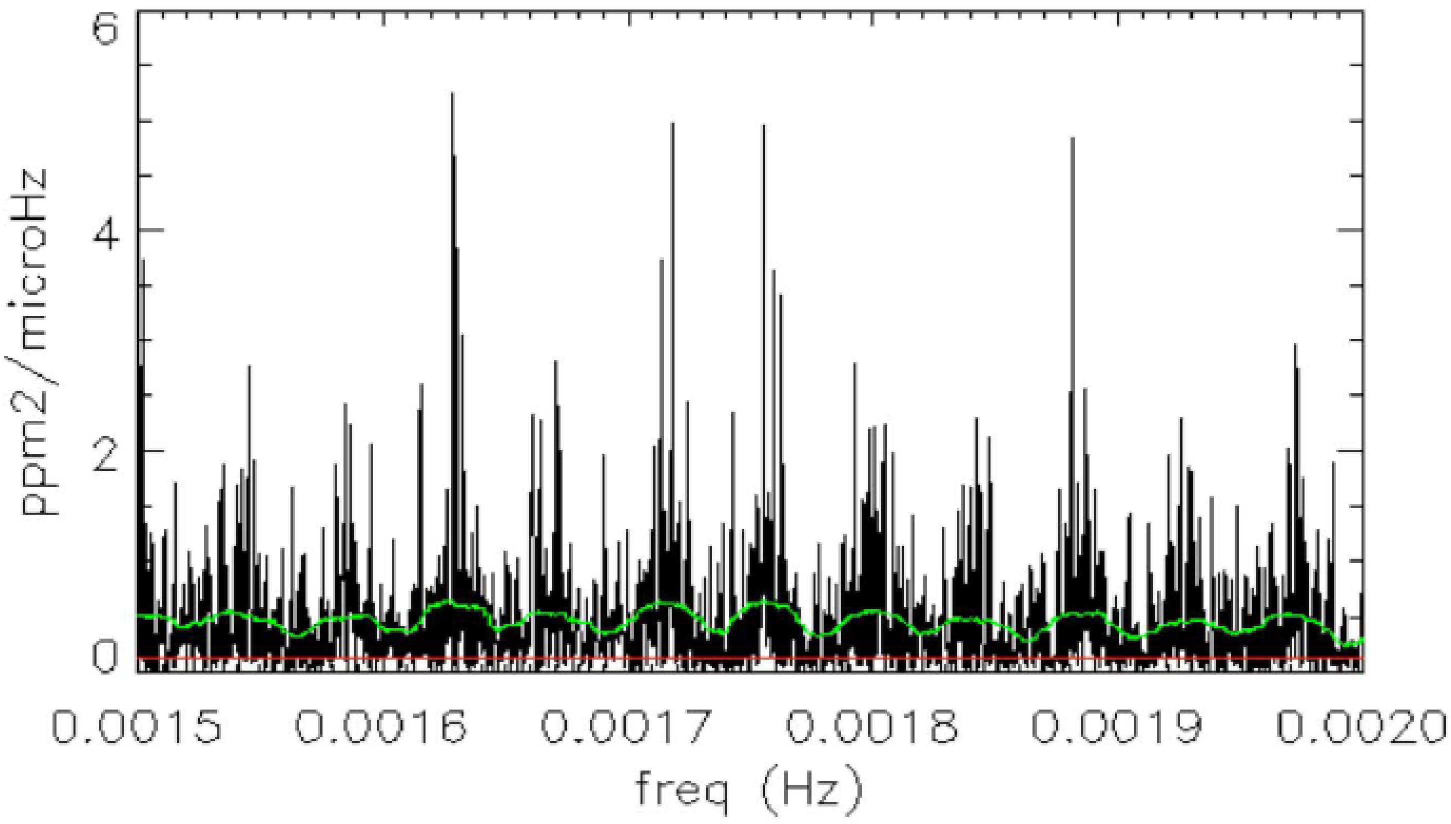
An 8th magnitude B star in an eclipsing binary



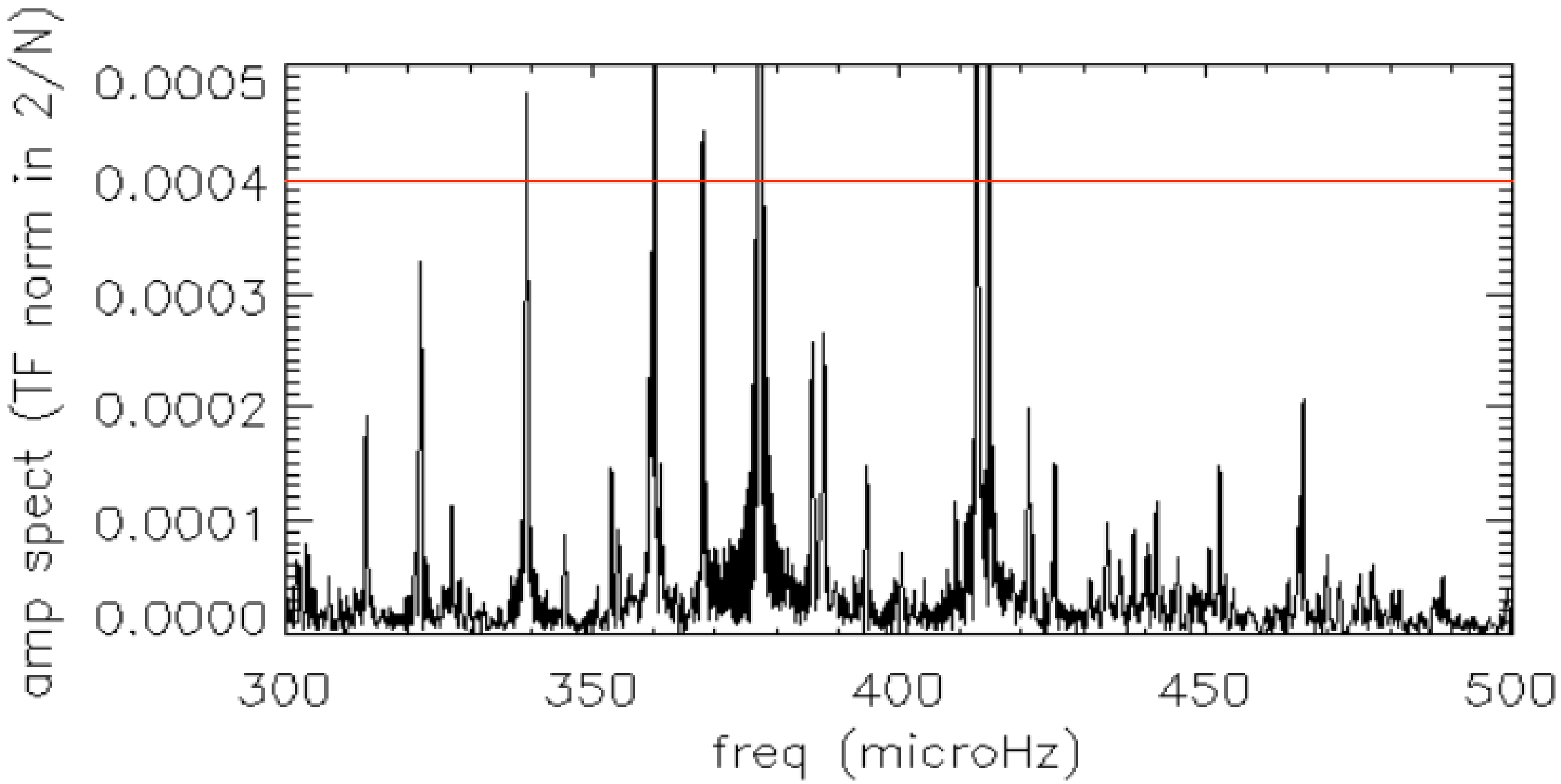
A 6th magnitude Be star showing daily variablity



HD 49933 observed with CoRoT



Fourier spectrum of a delta scuti star

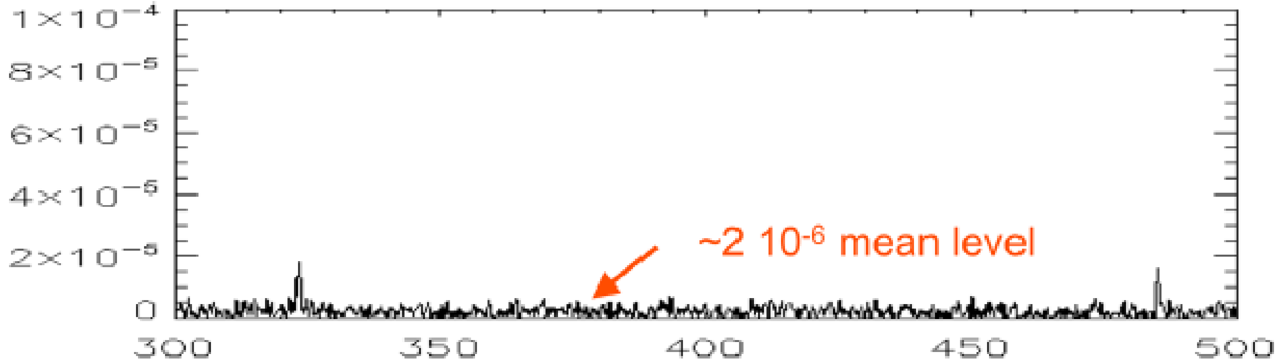


8th magnitude star.

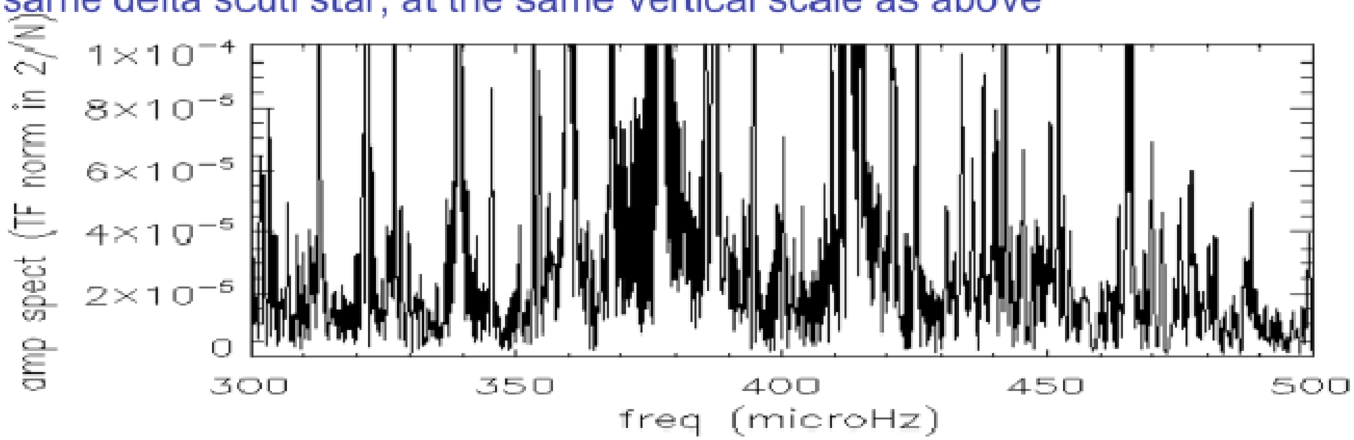
The red line illustrates the common lowest detection limit from the ground.

Noise in the low frequency range

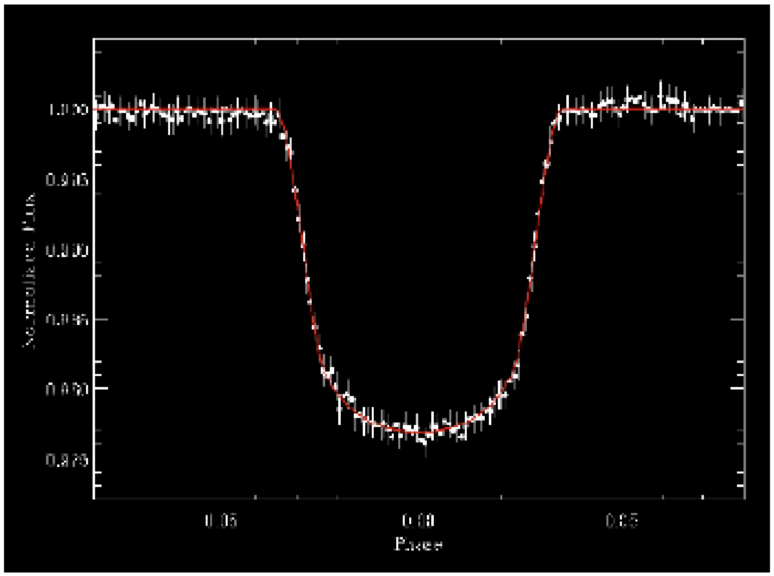
9th magnitude star indicative of the very low noise level in the low frequency range.



The same delta scuti star, at the same vertical scale as above



The first planet



Precision: 3 10-4 in 1 hour !
Observed 40 times!,
duration 2h

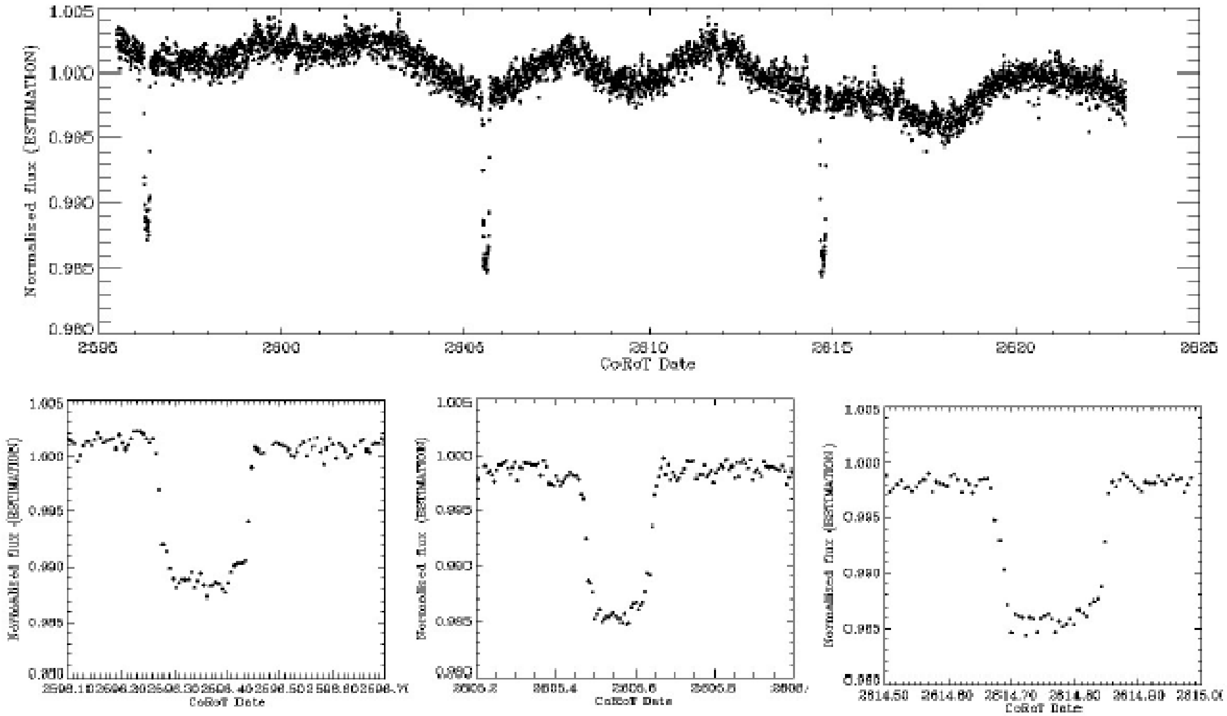
CoRoT-EXO-1b

Period: 1.5 day
Radius 1.5 to 1.8 R Jupiter
Distance to the star: 0.04 UA

Observed with SOPHIE (OHP)
Mass 1.3 M Jupiter (uncertain)

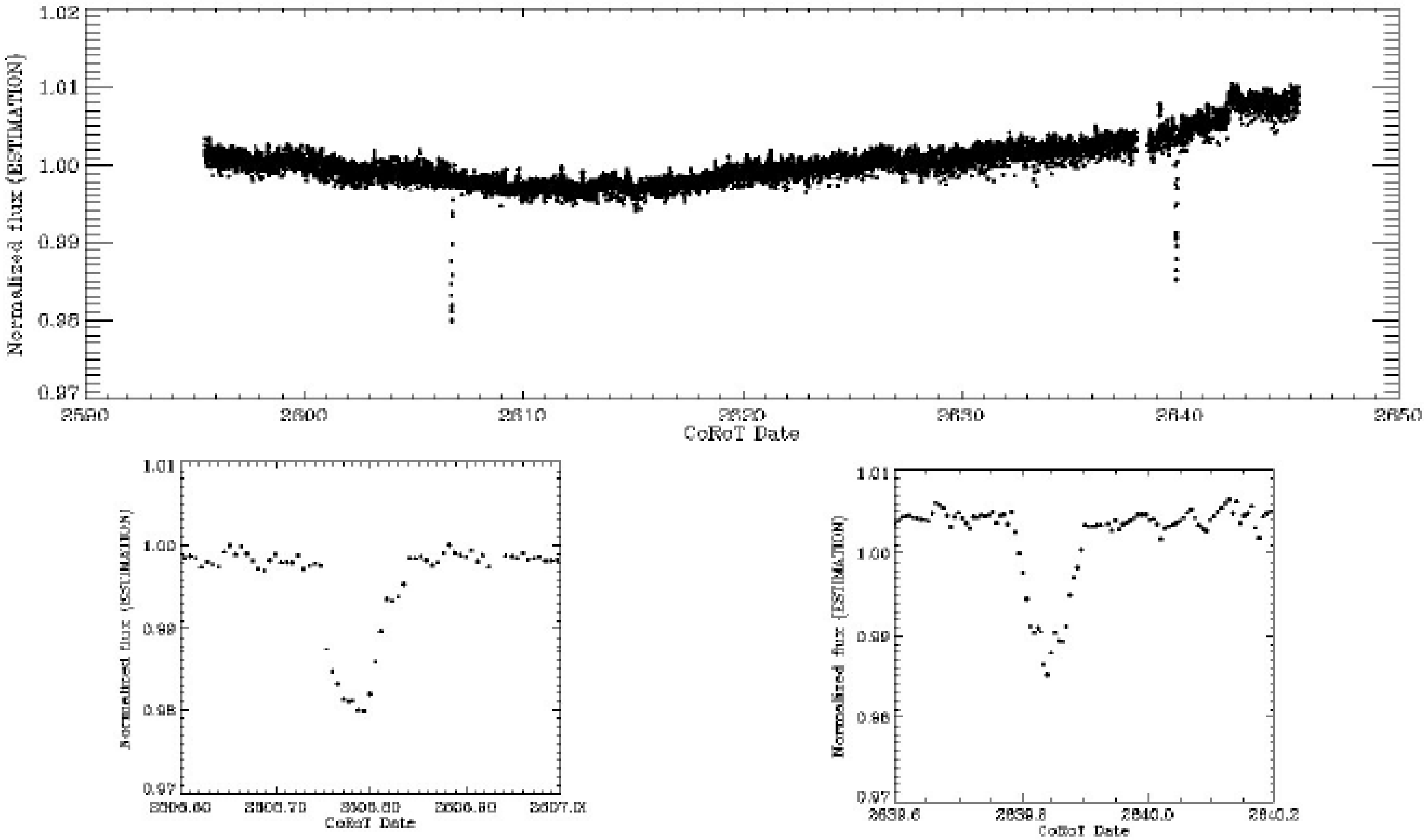
Dwarf solar like star mv=13

Planet candidate (1)



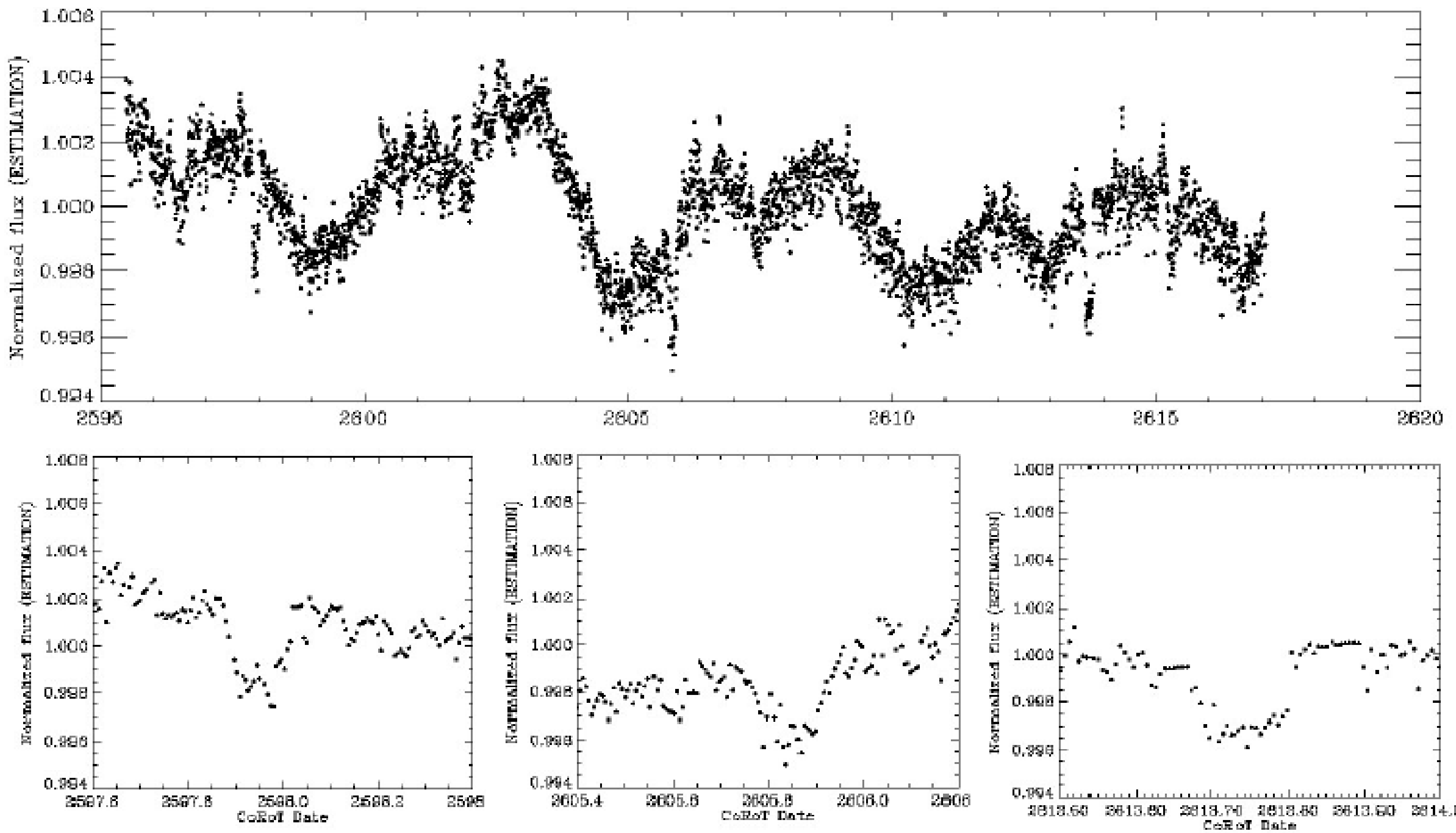
Period 9.03 days, Star FOV, Vmag 13.7, Initial Run

Planet candidate (2)



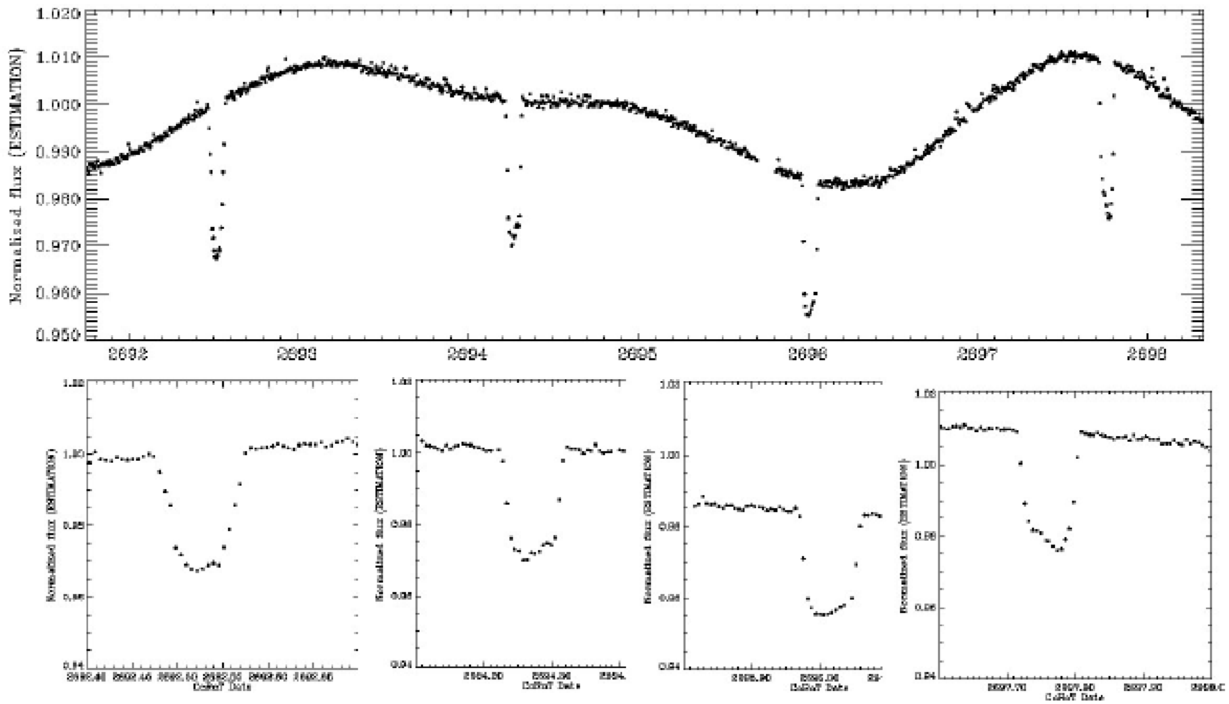
Period 33 days, Star G2V, Vmag 13.9, Initial Run

Planet candidate (3)



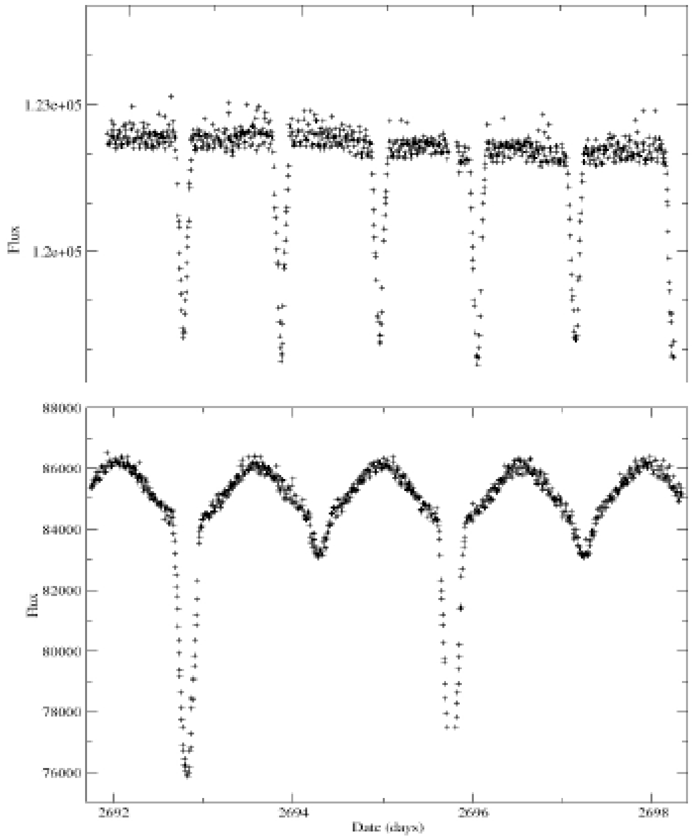
Period 7.77 days, G5V, Vmag 13.5, Initial Run

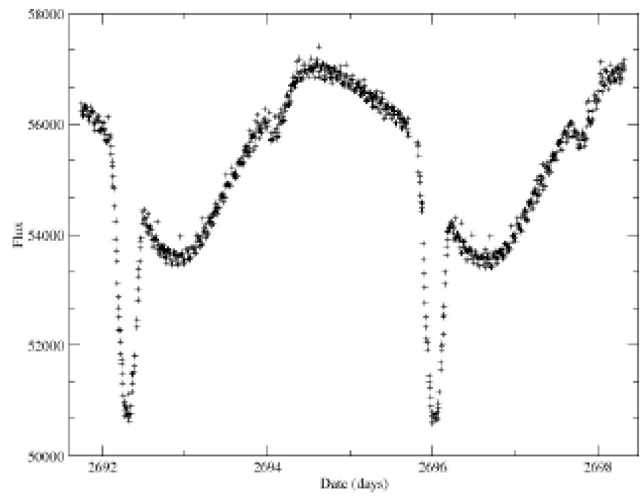
Planet candidate (4)



Period 1.74 days, K0V, Vmag 12.6, Long Run

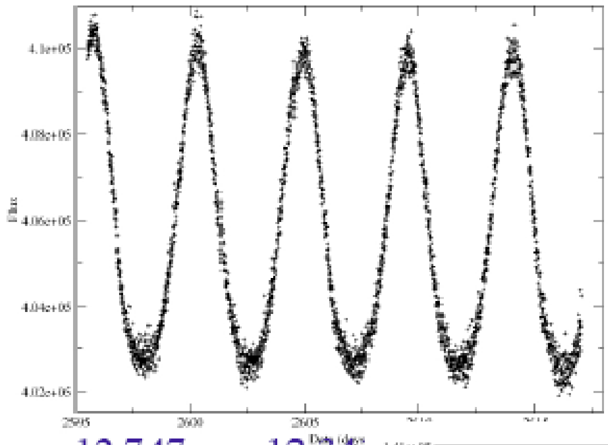
Ecclipsing binaries in the exo field



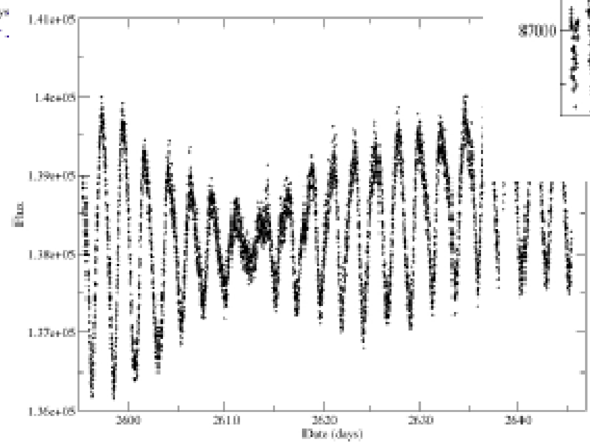


3 colors, sampling 512s (32s)

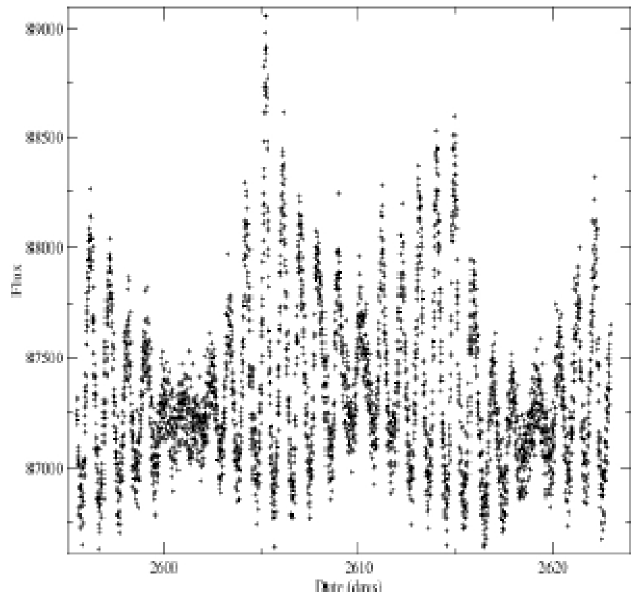
Pulsating variables in the exo field



m_B=12.747 m_V=12.34
m_R=11.174
Amplitude ~ 2 %,
period ~ 4 days

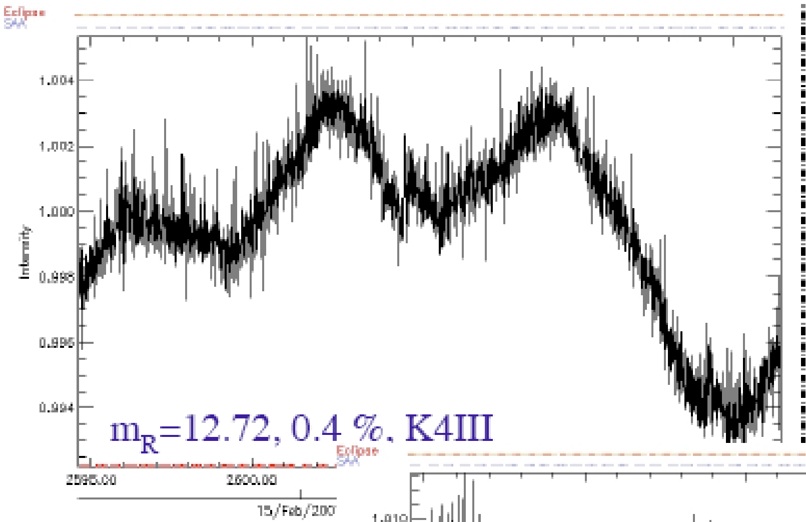


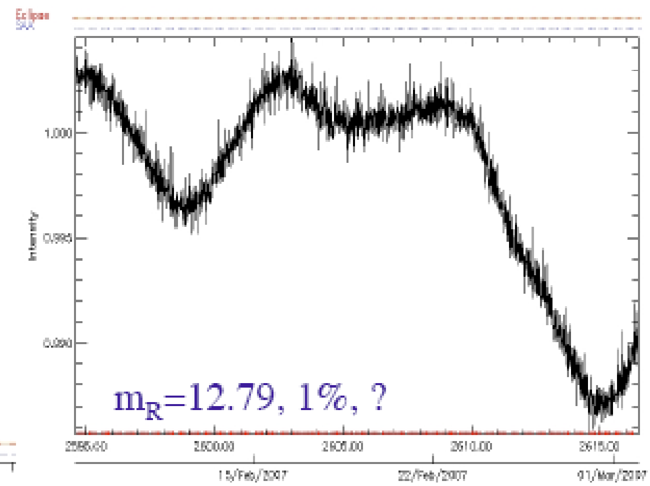
m_B=14.569 m_V=13.860, m_R=13.606
Amplitude ~ 3 %

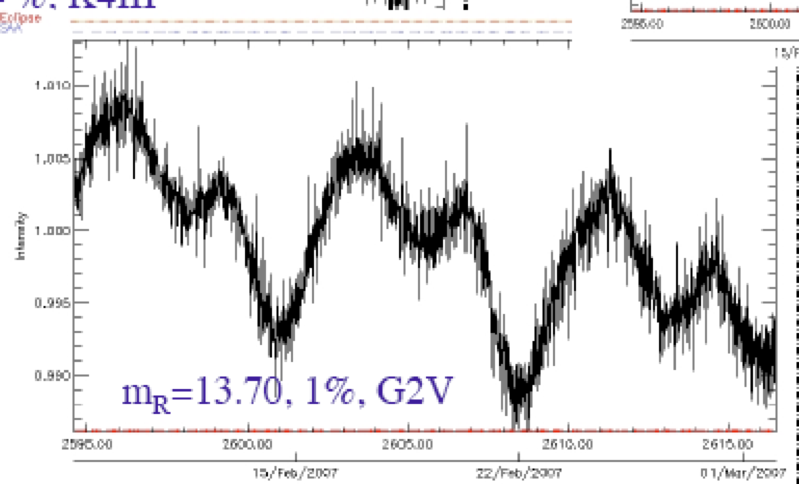


m_B=15.240 m_V=14.567, m_R=14.324
Amplitude ~ 20 %

Wait and see



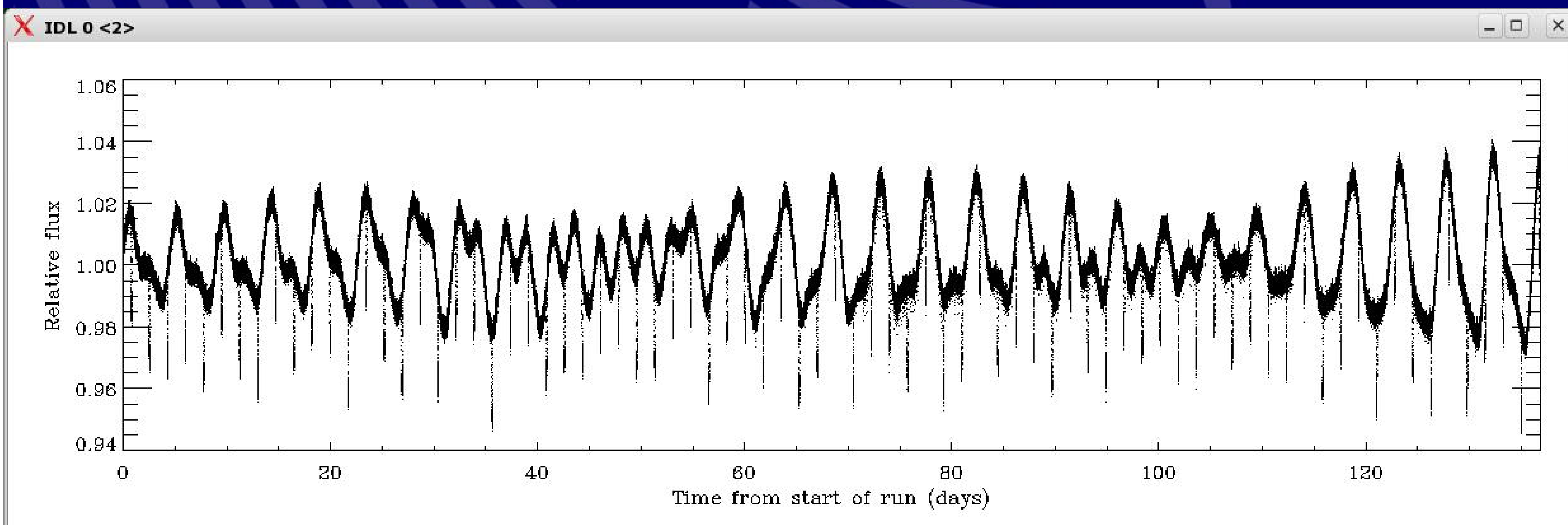




CoRoT Exo-2b

140 days of data, 78 consequtive transits

1.74 day period, R = 5 R_{O}, Star solar, low metallicity 5 + 40 day periodicity in starspots = differential rotation. 1 σ noise = 1.5 x 10^{-4} epoch folded



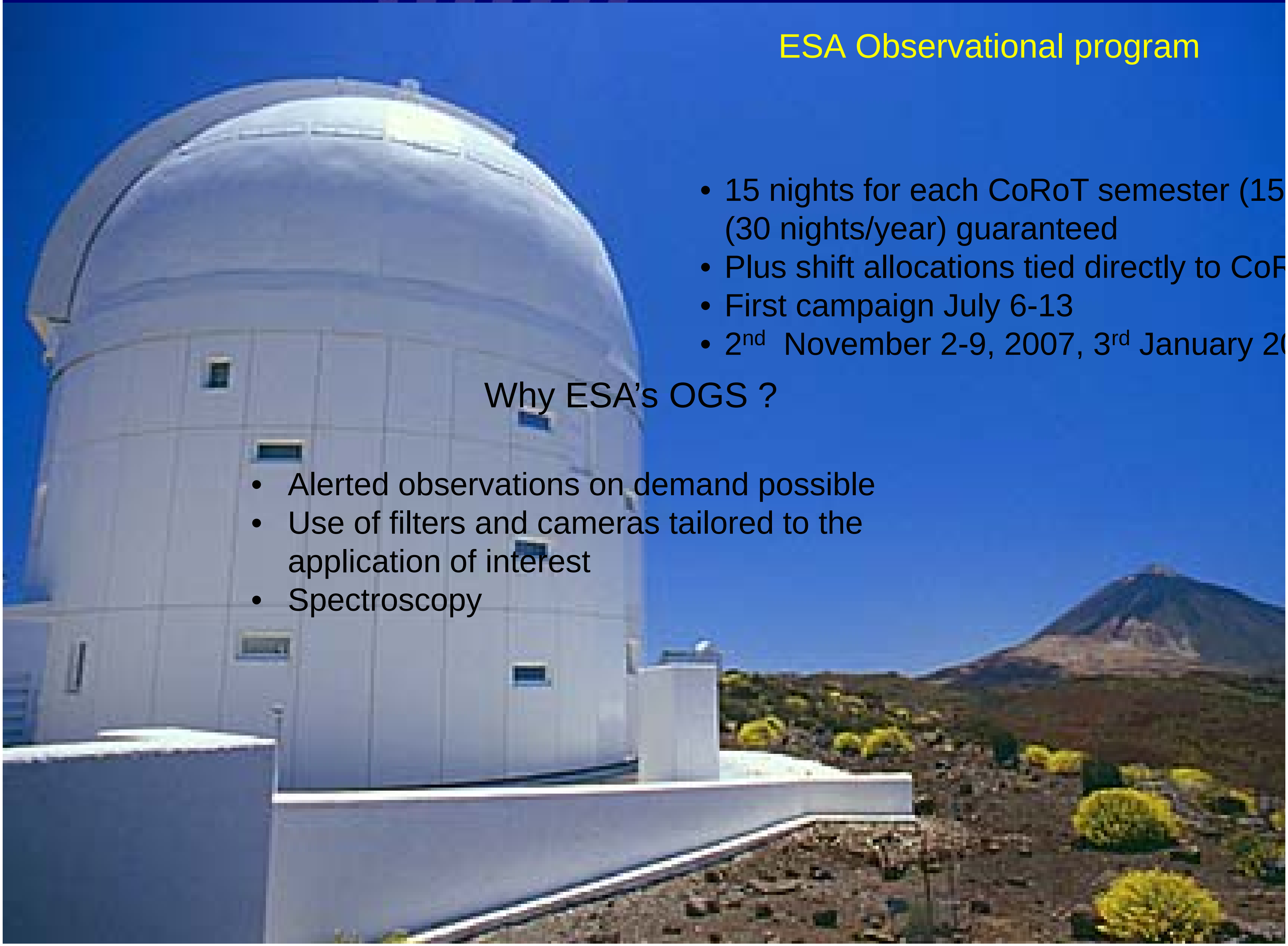
FuP Telescope observations

1. **ESO**: SUSI-2 (**NTT**); UVES, FORS, NACO (**VLT**), HARPS(**3.6m**), Euler, SOPHIE(**OHP**), ESPADON (**CFHT**)
2. Spectroscopy, RV, Stellar identification
3. FOW > CoRoT PSF, angular resolution > 0.6 arcsec, sensitivity < 20^{th} mag
   - High angular resolution On-Off photometry of background stars (ephemerides from CoRoT)
   - Re-measurement of transits (m_v=15.5) with higher sampling (< 8 min)

HST/SPITSER

esa

ESA Observational program



- 15 nights for each CoRoT semester (15
  (30 nights/year) guaranteed
- Plus shift allocations tied directly to CoR
- First campaign July 6-13
- 2nd November 2-9, 2007, 3rd January 2(

Why ESA's OGS ?

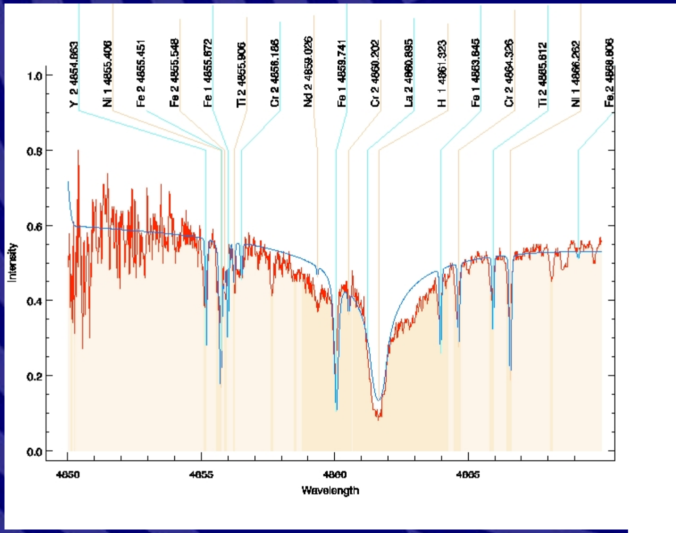
- Alerted observations on demand possible
- Use of filters and cameras tailored to the application of interest
- Spectroscopy

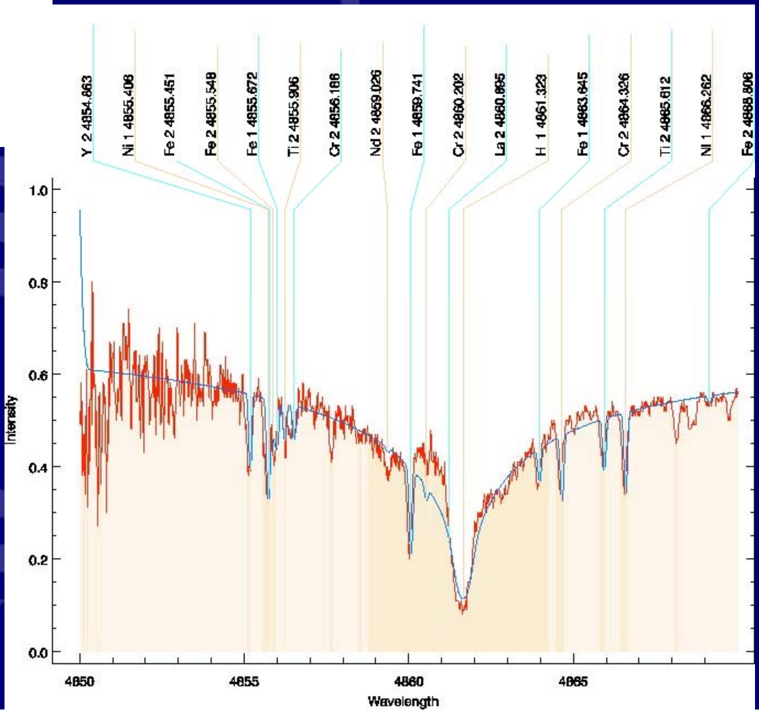
Planet size is modell dependent

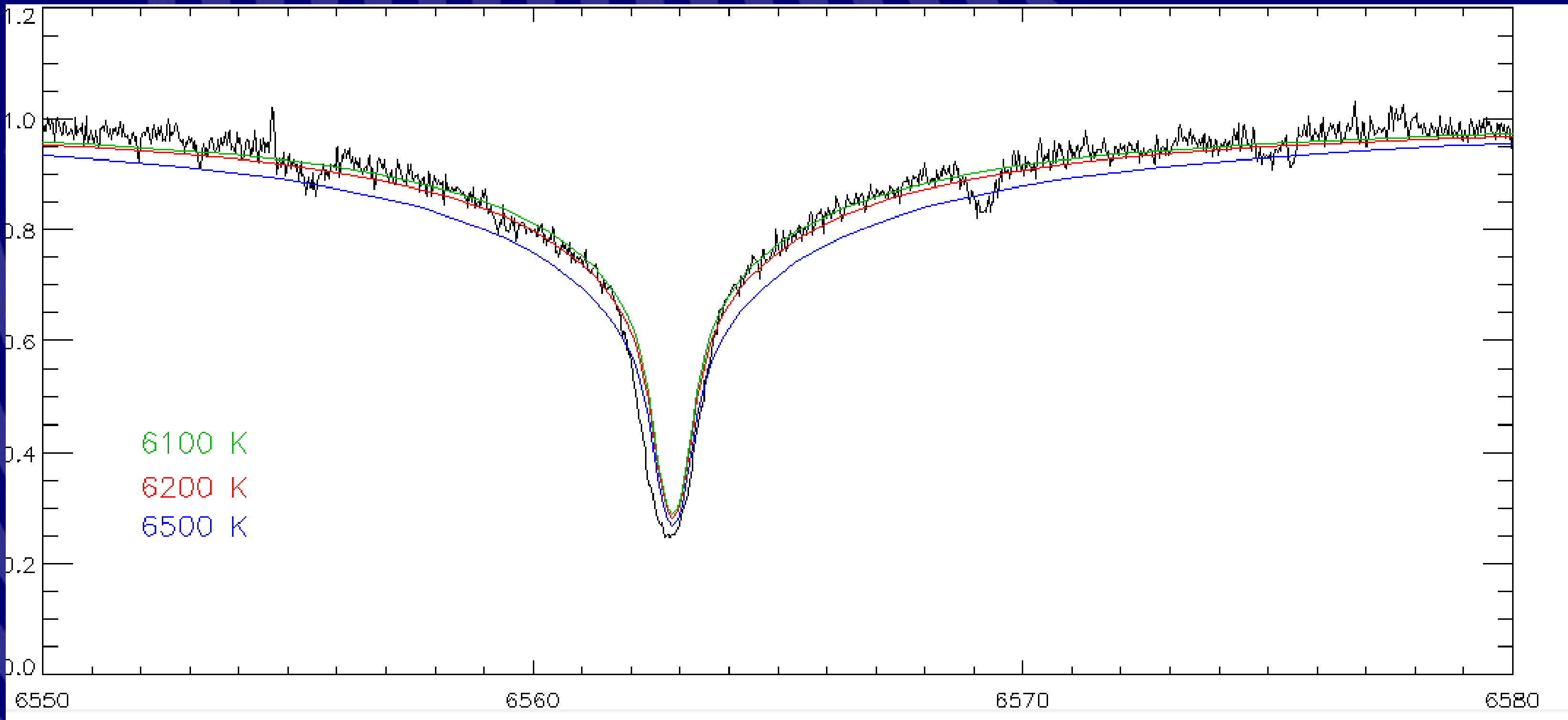
VALD data base

SME (LTE)

Observations (HARPS/UVES)







1.2
1.0
0.8
0.6
0.4
0.2
0.0
6550
6560
6570
6580
6100 K
6200 K
6500 K

Why is CoRoT so much better than specifications:

- EVRIS, PRISMA, STARS, Eddington
- PROTEUS Bus
- Luck?

What next: 2-5 years of operations!

Then more missions

The Future

So where do we (Europe) go from here?

Pale Blue Dot initiative -- Community building, analysis, etc

ESA task force on exoplanetology -- Roadmap to exoplanets and beyond

Samples of what is likely to happen: ==>

Darwin technology program on hold

New element:

-**ESA ExoPlanetary Roadmap Advisory Team**

- **Hatzes (Chair)**
- **Quirrenbach, Tinetti, Udry, Rauer**
- **Boccaletti, Dvorak, Micela, Selsis, Morbidelli**

Mission scenario

1.	CoRoT -- Transit mission	2006/9 (2012)
2.	Herschel KE-belt observations	2008 --
3.	Kepler -- Transit mission	2008(9) --
4.	PRISMA	2009
5.	PROBA-3	2010/11
6.	Darwin/TPF Precursor ? -- Direct observation, e.g. PLATO, small coronograph	2017
7.	SIM Planet finder	2020?
8.	Coronograph 2m	2020?
9.	Darwin/TPF -- Direct observation	2022?

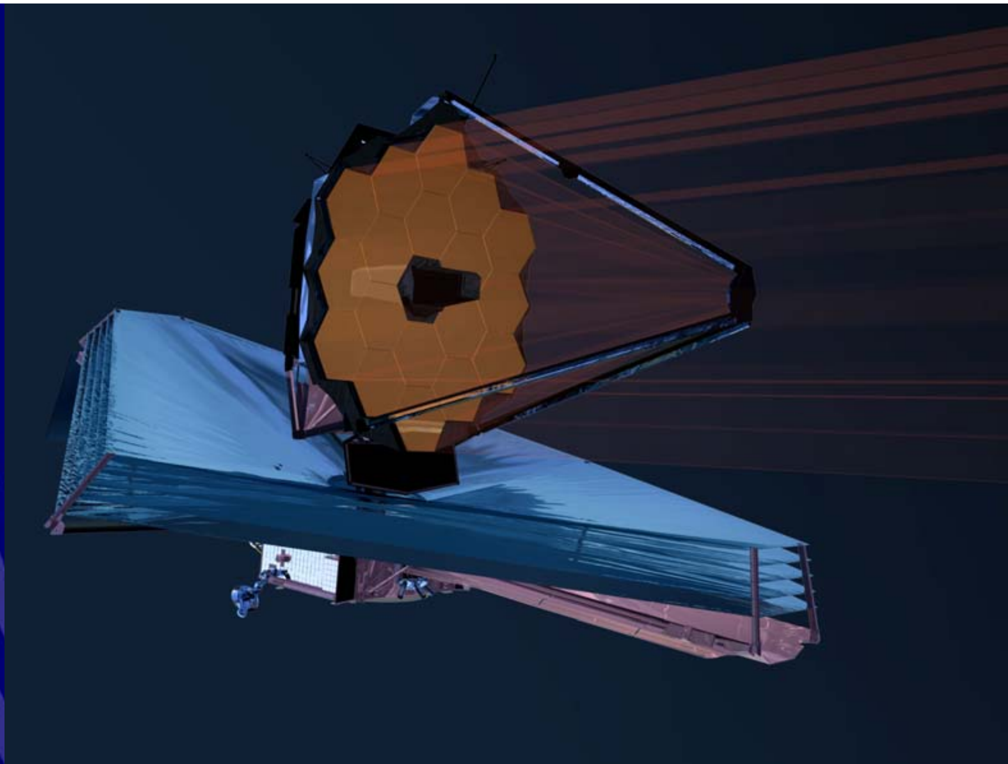
Herschel - 2008
Kuiper Edgworth-disks

- **HERSCHEL program**
  - **Building on Spitzer legacy**
  - **Unbiased search for Kuiper belts / exo-zodi in OT program of closest 200 FGK stars (d < 18pc).**
  - **Sensitivity is 1 Kuiper-belt around G2V at 10pc**
    with S/N of 5 in ~30 min.

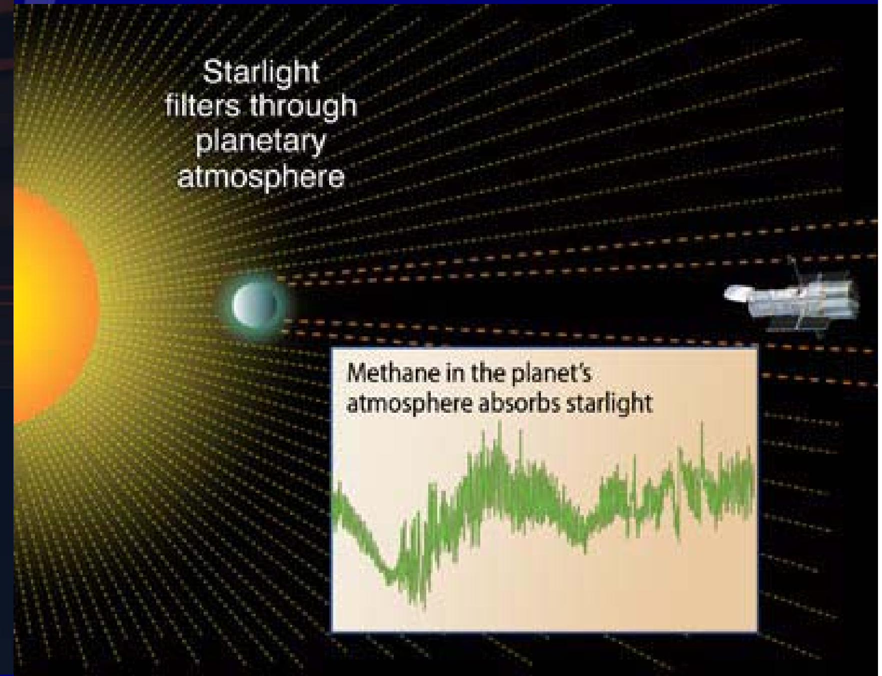
Disks as tracers of targets T=30-40K

KEPLER:

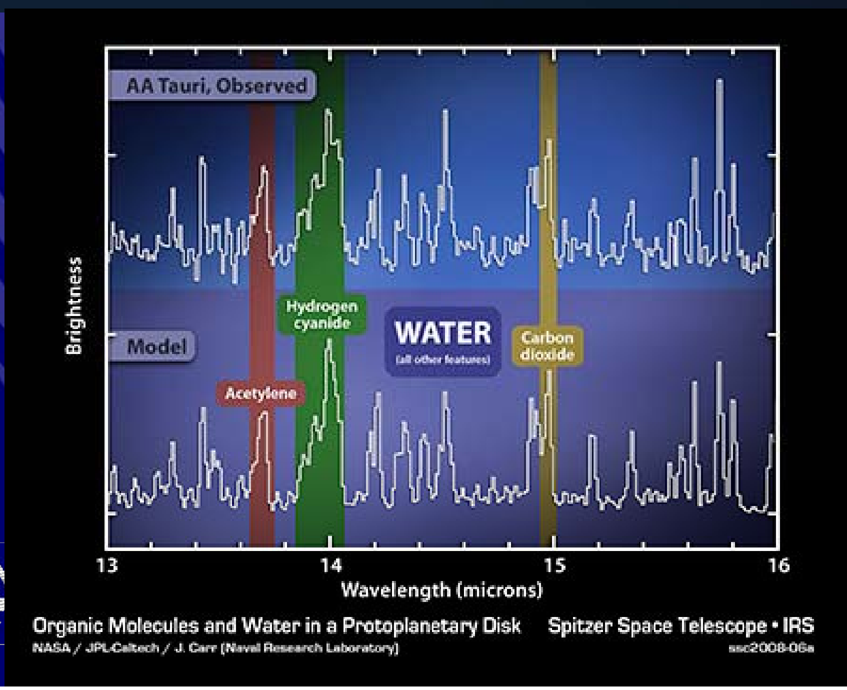
- Launch in 2009, results in 1-3 years, nominal mission time 4 years
- Scans 100,000 stars in a 150 sq. deg. field in Cygnus-Lyra
- Expected to find ~5-50 'real Earths'
  = 1 $R_{\oplus}$ in HZ = 1 AU around G2V)

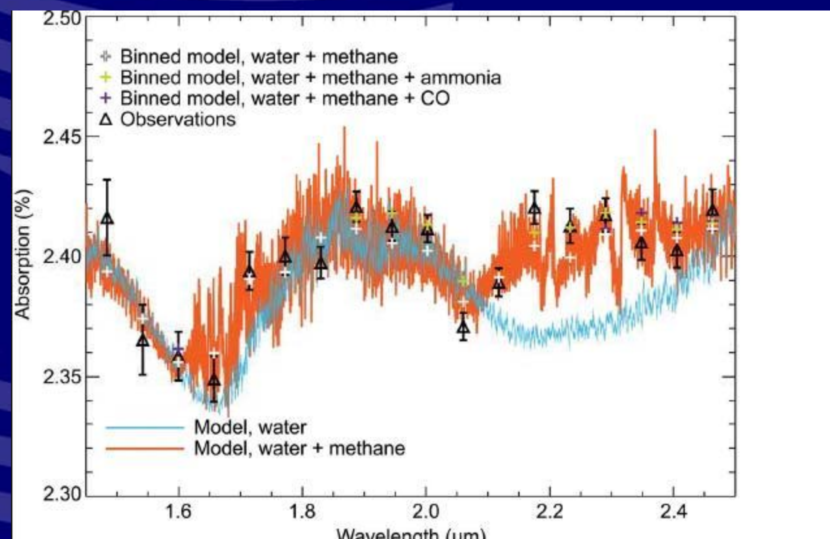


NIRSpec

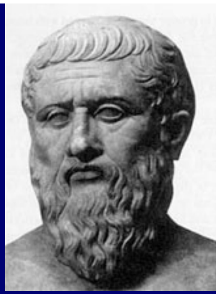


MIRI





PLATO science objectives



PLATO = *new generation mission of ultra-high precision photometry for exoplanet search and stellar seismology*

***main objective:** evolution of exoplanetary systems (planets + host stars)*

- *the evolution of planets and that of their host stars are closely linked*
- *a complete and precise characterization of host stars is needed to measure exoplanet properties: mass, radius, age*
- *compare planetary systems of different ages*
- *observe exoplanets at different stages of dynamical evolution*
- *… and at different stages of physical and chemical evolution*
- *correlation of planet evolution with that of the host stars*

= comparative exoplanetology

needed observations:

1. detection & characterization of planetary transits

2. seismic analysis of exoplanet host stars

3. complementary ground-based follow-up (spectroscopy)

PLATO main science requirements

- 3 star samples
  1. ≥ 100,000 bright stars $m_V \leq 11$, with noise <2.7 10^{-5} per hr::
     exoplanets with radius smaller 1 earth
     complete seismic analysis of host star (mass, radius, age)
  2. ≥ 400,000 stars $m_V \leq 14$, with noise <8.0 10^{-5} per hr:
     exoplanets with radius down to 1 earth
  3. 1000 stars $m_V \leq 8$:
     asteroseismology in two colours

- two successive fields: 3 yrs (field 1) + 2 yrs (field 2, goal 3 yrs)

- field of view > 550 deg^2

- additional step & stare phase 1yr: 4 fields x 3 months

- duty cycle ≥ 95%

proposal included 2 options: staring and spinning

staring has been baselined
for maximizing number of exoplanets with complete seismic analysis of host star

Exoplanets: photometric transits

known exoplanets

PLATO

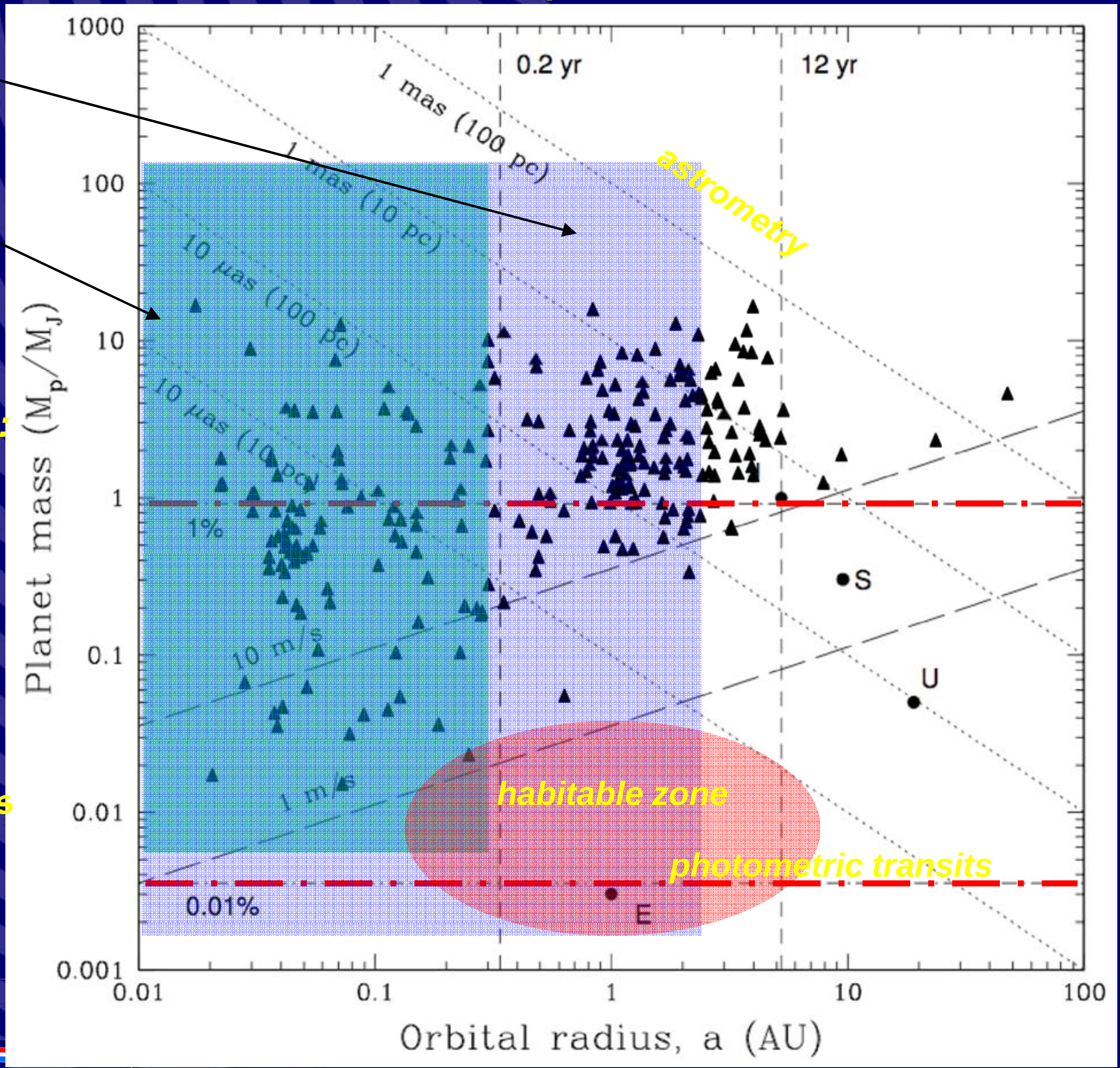
CoRoT

3 advantages of transit method:

- detect telluric planets

- measure their radius

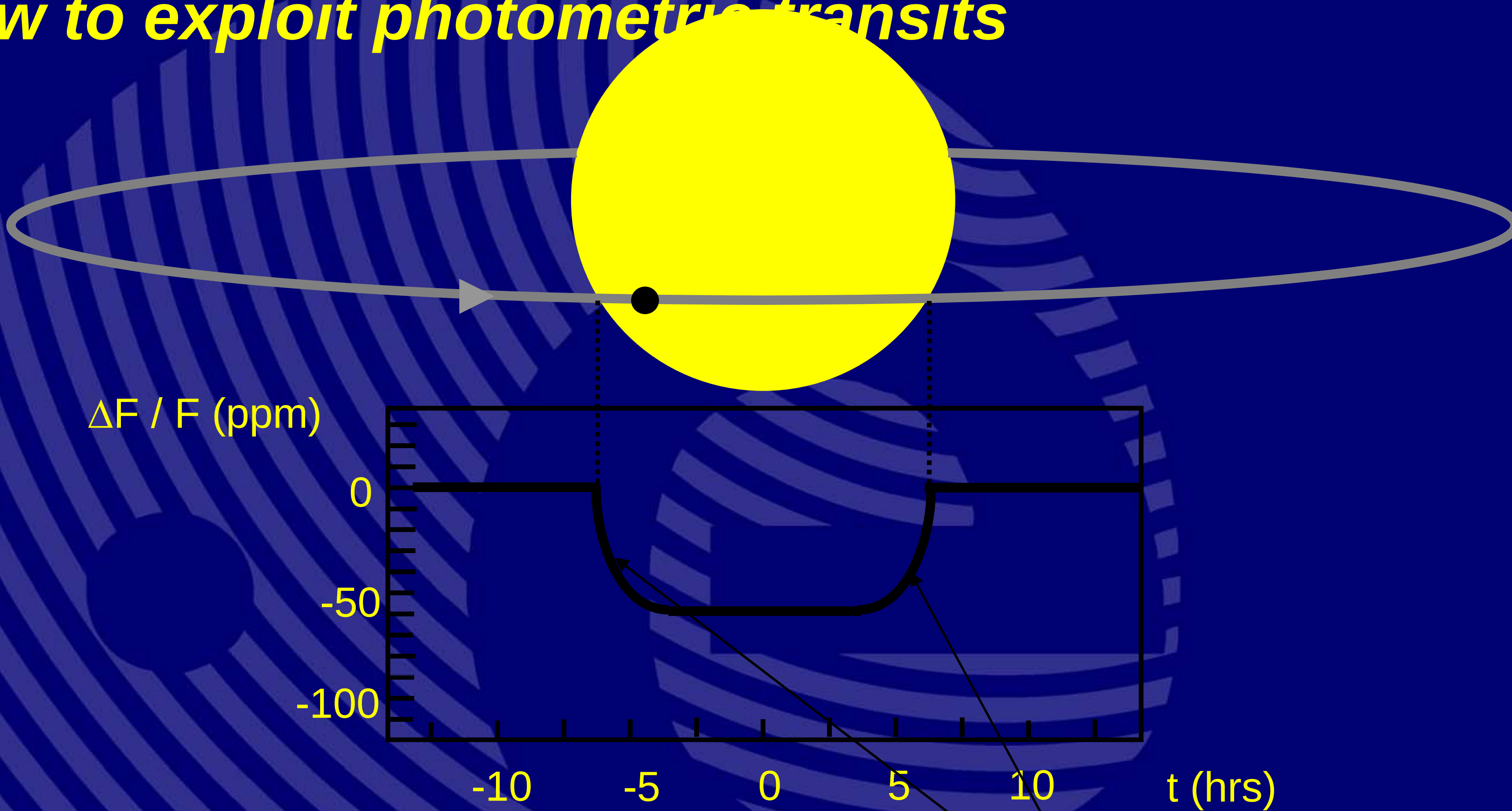
- orbit inclination is known



radial velocities

esa

how to exploit photometric transits



P: period; R_*: star radius; a: semi major axis; β: transit latitude

geometrical probability : $Pr = R_*/a$

transit duration : $Tr = (P/\pi)\,(R_*/a)\cos\beta$

transit depth : $\Delta F/F = (R_p / R_*)^2$

Kepler third law: $M^{1/3}/R_* = (4\pi^2/GP^2)^{1/3}\,(a/R_*)$

1. *β from transit profile*
2. *R_*/a from transit duration*
3. *R_p/R_* from transit depth*
4. *$M^{1/3}/R_*$ from 3rd law*

(5. $M_p/M_*^{2/3}$ from Vrad)

R_p, a, M_p, age (planet) can be determined if R_*, M_*, age (star) are measured

Seismic analysis of planet host stars

1. radius and mass

radius from Gaia
seismology ⇒ $\rho(r)$,
in a a model independent way:

$\nu_{nl} = f\ (c^2 = \Gamma_1 P/\rho)$

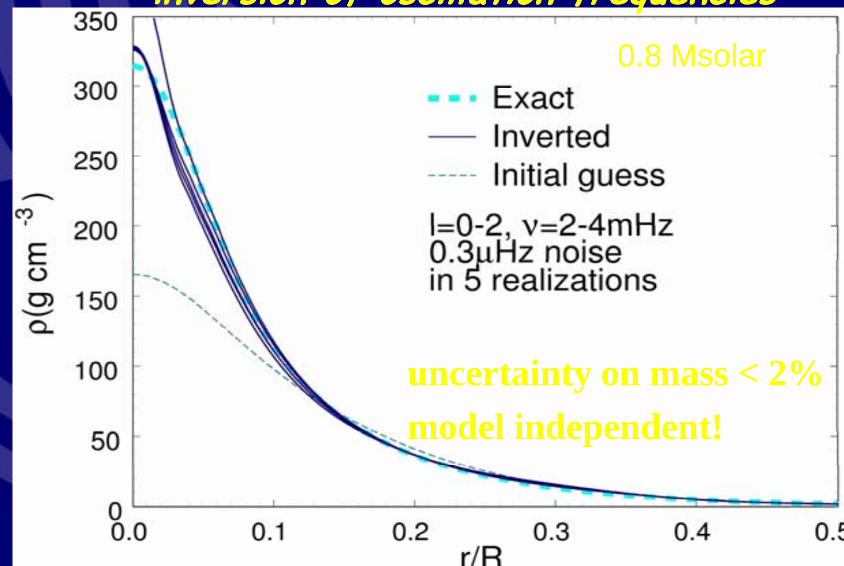
$\nu_{nl} \Rightarrow \rho(r)$

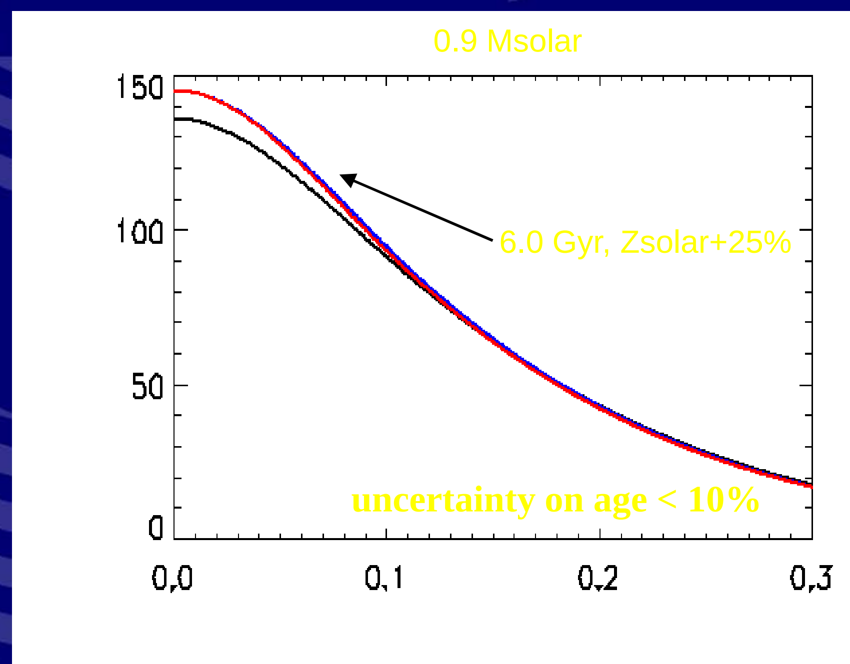
2. age

modelling: evolution ⇒ He+metal content ⇒ μ ⇒ ν_{nl}

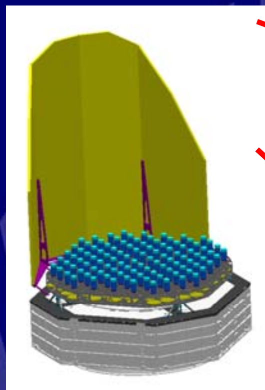
model dependent
(in particular initial chemical composition),
but final age uncertainty remains small:
< 10% , i.e. much smaller than classical determination (50-100% uncertainty)

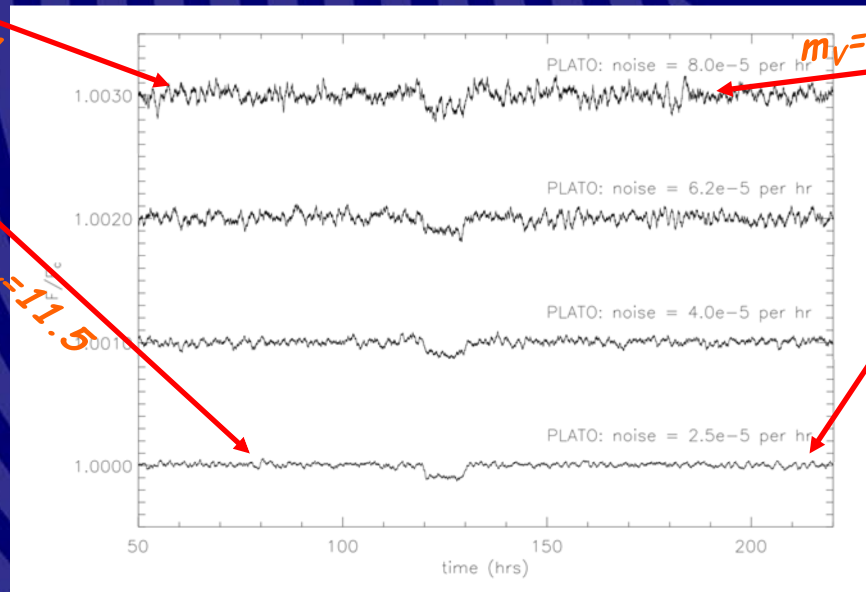
inversion of oscillation frequencies

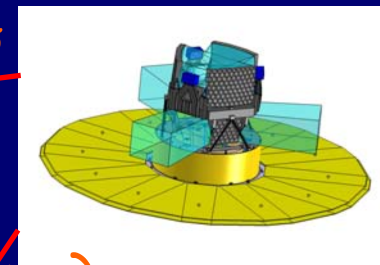




PLATO the two concepts







staring concept:
100 identical
10cm pupil telescopes
0.75 m^2

> 90% duty cycle
4 years on single field
+1 year step & stare

very high precision
simultaneous seismo+exo
redundancy
flexibility
high dynamical range

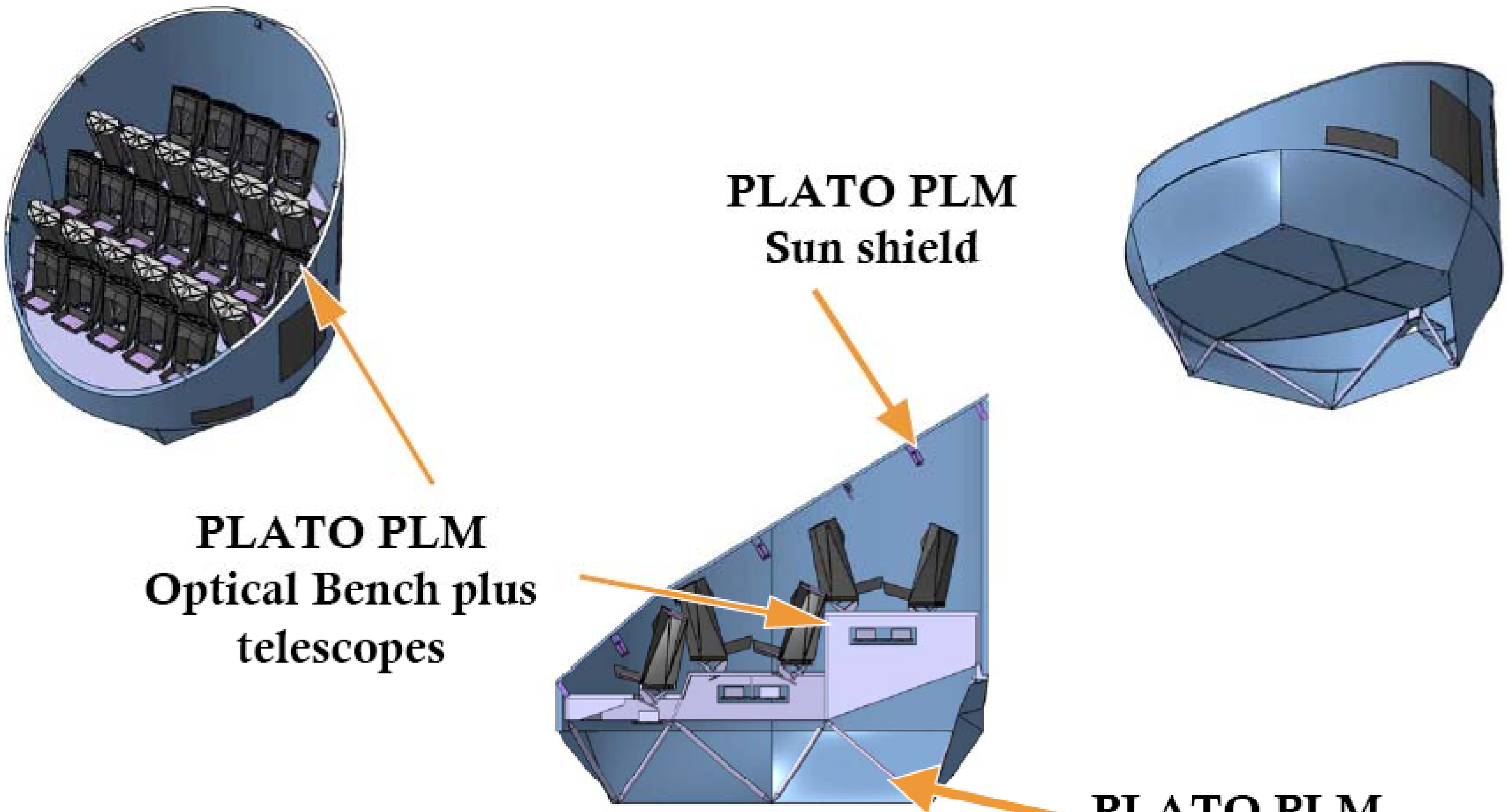
noise		#		mag
ppm/hr	ppm/30 d	stars	dwarfs	range
10	0.4	10,000	5,200	9.3-9.9
15	0.5	21,000	11,000	10.1-10.7
20	0.7	49,000	25,000	10.7-11.3
26	1.0	101,000	52,000	11.3-11.9
53	2.0	263,000	137,000	12.8-13.4
81	3.0		360,000	13.7-14.3
100	3.7		410,000	14.2-14.7

spinning concept:
3 identical
0.72 m^2 telescopes

gal. plane exploration
high dynamical range

monitoring 30s/7min
6 m/yr spinning
6 m/yr step & stare
5 year duration

noise		#		mag
ppm/hr	ppm/30 d	stars	dwarfs	
search mode, duration 1825 days				
50		55,600	28,900	10
81		144,000	75,000	11
130		240,000	125,000	11.5
fine mode, duration 30 days				
20	0.7	85,000	44,000	11


PLATO PLM
Sun shield
PLATO PLM
Optical Bench plus
telescopes
PLATO PLM
to SVM I/F

PLATO performances

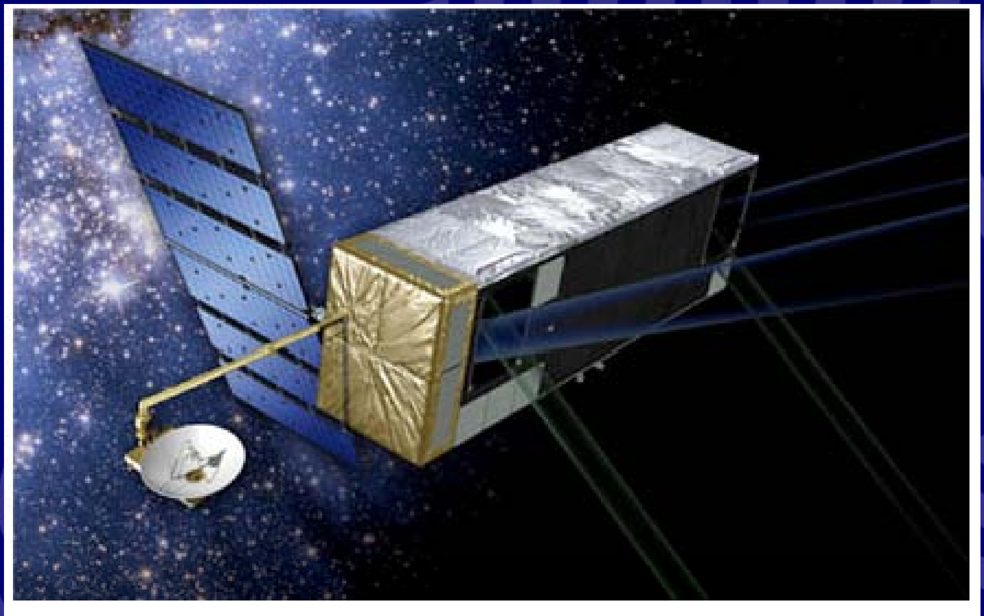
(pessimistic) estimate of PLATO performances,
taking into account contamination by neighbouring sources:

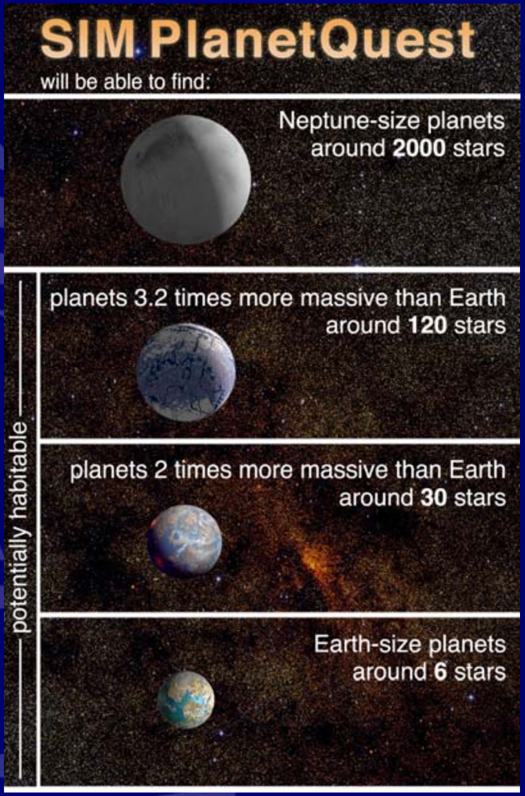
	PLATO			*Kepler*	
noise level (hr^{-1})	# of stars	# of MS stars	average magnitude	# of MS stars	average magnitude
$2.7\ 10^{-5}$	78,000	47,500	10.5	12,000	12.2
$3.6\ 10^{-5}$	98,000	60,000	11.0	16,000	12.8
$8.0\ 10^{-5}$	619,000	378,000	12.2	100,000	14.0

detection of telluric exoplanets, including in the habitable zone, with complete characterization of host stars (radius, mass, age)

PLATO-exo
= 10 x CoRoT
= 4 x Kepler (at given noise level)
= 30 x Kepler (at given magnitude)

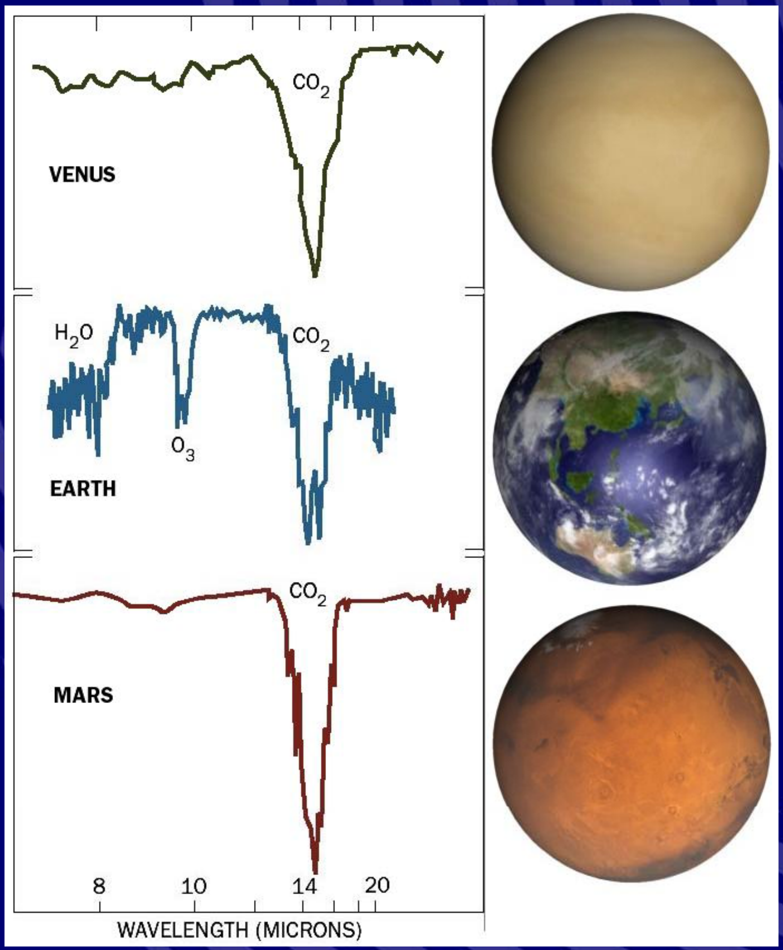
PLATO-seismo
= 1000 x CoRoT
= 200 x Kepler

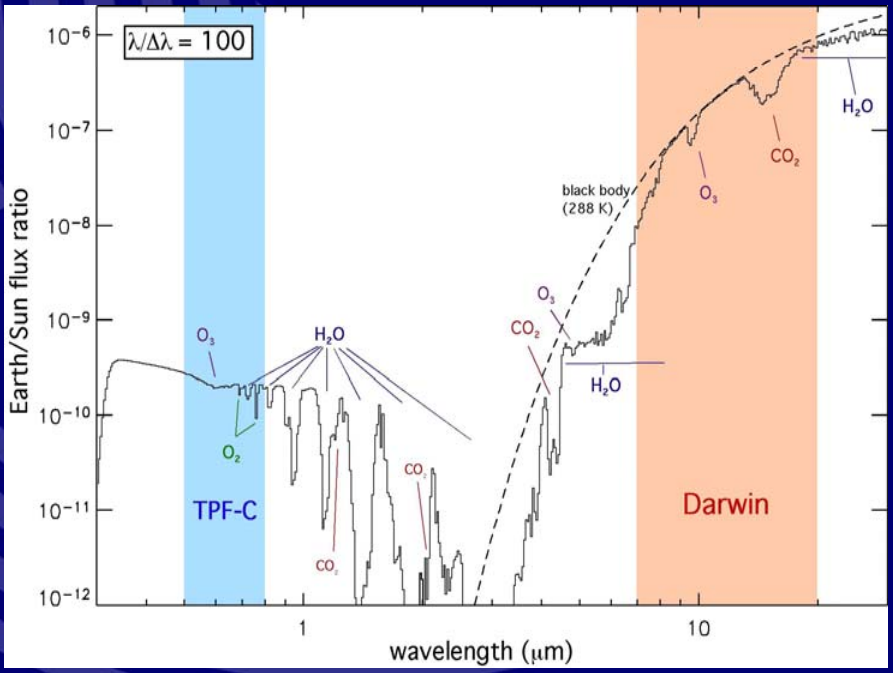




SIM - the mission that refuses to go away

Bio markers





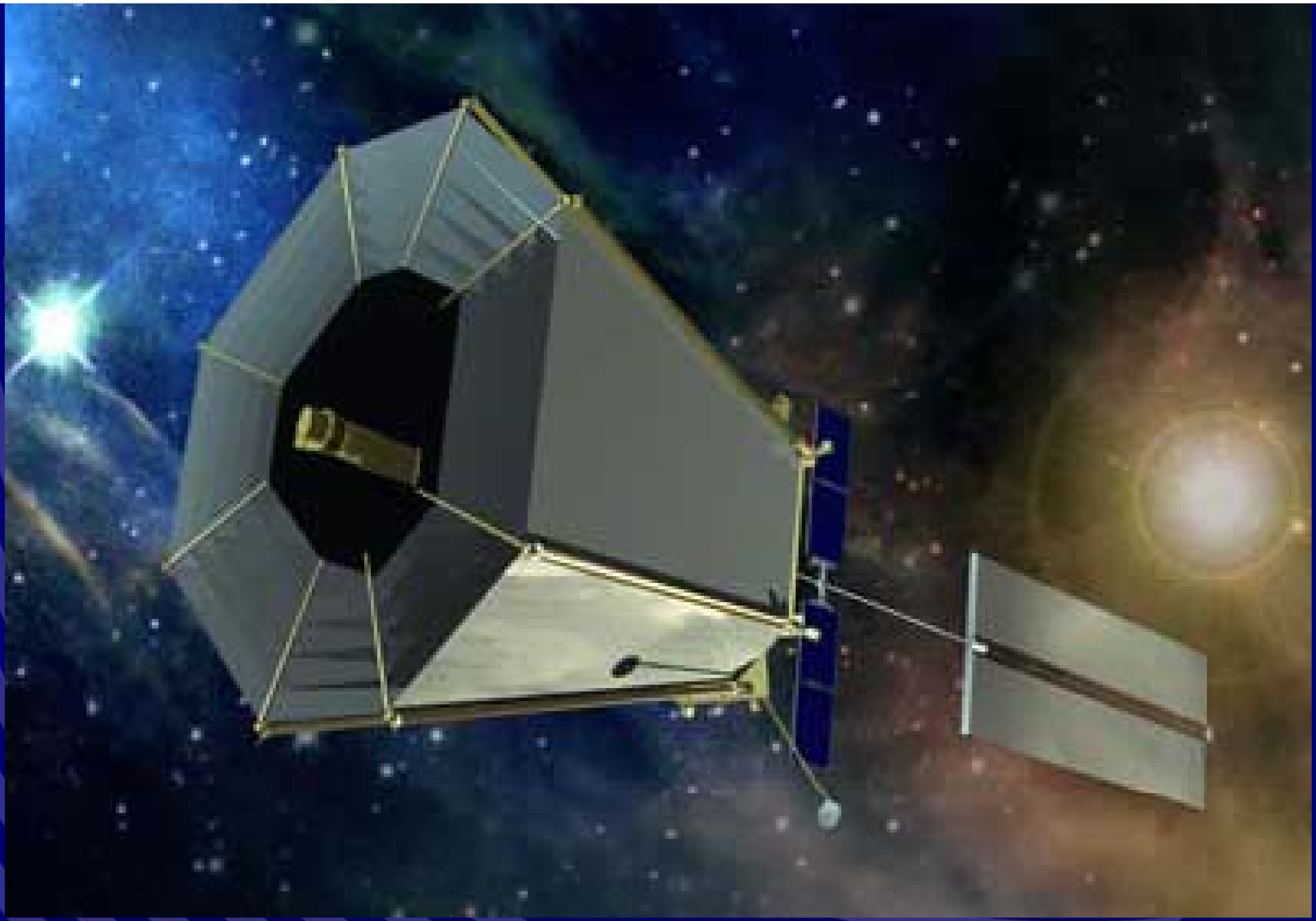
The goal is to find rocky planets with an atmosphere out of photo-chemical balance.

(cf. Lederberg, 1965 and Lovelock, 1965)

Working definition:

Life º $O_3 + H_2O + CO_2$

Ideally, detect reduced molecules (CH_4, N_2O) as well

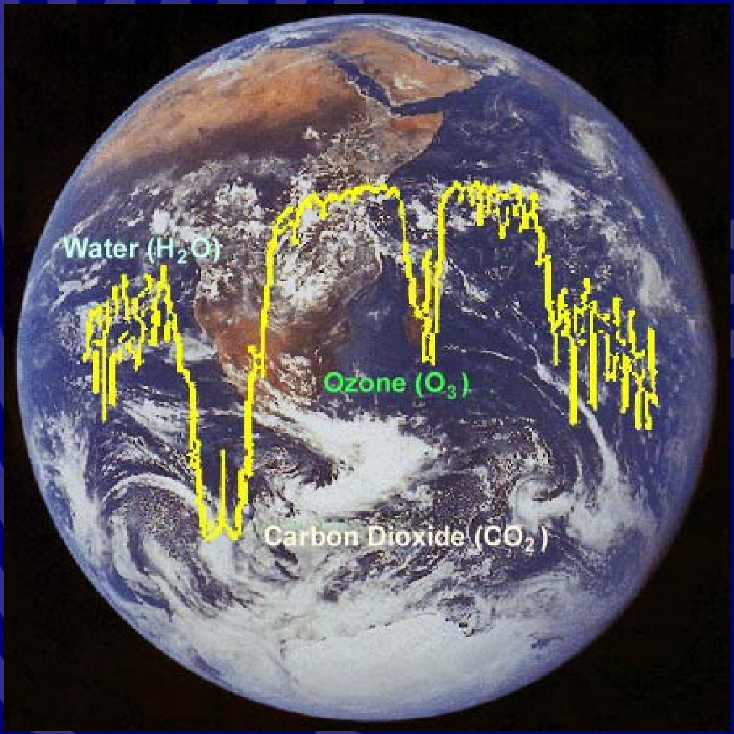


US medium and/or large size coronograph

Darwin/TPF-I Mission
direct observation!

Cosmic Vision -- Large mission - requires ESA-NASA collaboration

DARWIN logo



There is a long way to go: ”This is not the end, not even the beginning of the end, but maybe, just maybe it is the end of the beginning…..” (Winston Churchill)

The Ultimate Goal -acheived in 202X?

esa